STATE OF KANSAS
BEFORE THE DIVISON OF WATER RESOURCES
KANSAS DEPARTMENT OF AGRICULTURE

In the Matter of the City of Wichita's Phase II Aquifer Storage and Recovery Project In Harvey and Sedgwick Counties, Kansas	))))	**Case No. 18 WATER 14014**

Expert Report by Tim Boese
for
Equus Beds Groundwater Management District No. 2

February 18, 2019

Introduction

As manager of the Equus Beds Groundwater Management District No. 2 (District), the purpose of this Expert Report is to provide my expert analyses and opinions regarding the City of Wichita ASR Permit Modification Proposal (dated March 12, 2018) as submitted to the Chief Engineer, Division of Water Resources. This Expert Report is provided to the District for the formal phase of the Public Hearing to be held before the Chief Engineer, Division of Water Resources.

Qualifications

I have been employed with the District in varying capacities since 1992, including Hydrologic Technician from 1992 – 2005, Hydrologist from 2005 – 2007, Interim Manager for parts of 2006 and 2007, and Manager from November 2007 to present. I have a Bachelor of General Studies from Fort Hays State University. During my employment with the District, my primary responsibilities have been varied and extensive including, but limited to: Data collection including, but not limited to, water-level measurements, water sample collection and water quality laboratory analyses, field inspections and investigations including, but not limited to, water quality investigations, compliance investigations, water meter inspections, and abandoned well inspections, monitoring well design and installation, regulatory compliance, drafting new District regulations, interpretation and enforcement of water related statutes and regulations, providing information and recommendations to the District Board of Directors, assisting District water users and landowners with groundwater related issues, providing groundwater technical and legal advice, performing safe yield and spacing evaluations, water permit application assistance, review, and processing, report writing, and review of engineering and hydrologic reports and models. I am an expert on the Equus Beds Aquifer, groundwater management, Kansas groundwater law and associated rules and regulations. Additionally, I have served on numerous committees, providing both groundwater management and technical advice to the following committees and associations, including:

1. Kansas Corporation Commission Oil & Gas Advisory Committee
2. NRCS Kansas Technical Committee
3. City of Wichita Water Utilities Advisory Committee
4. Sedgwick County Stormwater Technical Advisory Committee
5. Kansas Geological Survey Advisory Council
6. Kansas Groundwater Management Districts Association (KGMDA)
7. Groundwater Management Districts Association (GMDA)

My CV is attached. My hourly rate for expert testimony is $175 per hour.

Report Summary

This Expert Report includes background information about the City of Wichita Aquifer Storage and Recovery (ASR) Project, information about the City of Wichita ASR Permit Modification Proposal that was submitted by the City to the Chief Engineer, Division of Water Resources (DWR) on March 12, 2018, my analysis of the Proposal based on my expertise and opinion, and conclusions.

Aquifer Storage and Recovery Project Background

The history of the ASR Project is long and storied, and dates back to the early 1990's when the concept was first conceived between the City of Wichita (City), the City's consultants, and the District staff. The ASR Project history is too immense to completely describe in this report, but it involves many facets including a demonstration project in the mid 1990's, development of ASR rules and regulations, review and approval of ASR Phase I and Phase II water permits and injection permits, development and approval of two Memorandums of Understandings (MOUs) between the City and the District (one each for ASR Phase I and Phase II), construction of the existing ASR Phase I and Phase II facilities, monitoring, reporting, and annual accounting report to determine available recharge credits. The District, including myself, has been extensively involved with all aspects of the ASR Project. Given my long tenure with the District, I am probably one of the few individuals that has been intimately involved in the ASR Project from its inception until now, which gives me unique experience and qualifications to provide an expert opinion.

ASR Phase I

In addition to numerous water permit applications related to the ASR Phase I Project approved by Chief Engineer David Pope, on August 8, 2005, the Chief Engineer also issued an Initial Order, which set forth the Findings, Conclusions and Order for ASR Phase I. The Initial Order specified the terms, conditions, and limitations of the ASR Phase I project. The ASR Phase I project currently consists of one surface water intake, three bank storage wells, five recharge and recovery wells, and one active recharge basin.

The ASR Phase I Initial Order contains 51 Findings, 32 Conclusions, and 24 Order conditions, all as determined by the Chief Engineer. The individual water permits issued by the Chief Engineer also include several conditions and limitations. Particularly relevant to this review and report, the Chief Engineer made certain findings, conclusions, and decisions regarding passive recharge credits and the minimum Index levels, which will be discussed later in this report.

On August 1, 2006, the Chief Engineer issued a Findings and Order (Modified Order), modifying certain conditions of the August 8, 2005 Initial Order for the ASR Project. The Modified Order was issued to reflect the inclusion of a surface water pumpsite, as four of the original bank storage well permits were being dismissed and replaced with a surface water permit. The Modified Order did not materially change the Initial Order, other than to include the surface water pumpsite into certain conditions.

ASR Phase II

In addition to numerous water permit applications related to the ASR Phase II Project approved by Chief Engineer David Barfield, on September 18, 2009, the Chief Engineer also issued a Findings and Order, which set forth the terms, conditions, and limitations of the ASR Phase II project.

The ASR Phase II project currently consists of one surface water intake and treatment plant, 30 recharge and recovery wells, and one active recharge basin.

The ASR Phase II Initial Order contains 16 Findings and 17 Order conditions, all as determined by the Chief Engineer. The individual water permits issued by the Chief Engineer also include several conditions and limitations. Particularly relevant to this review and report, the Chief Engineer made certain findings and decisions regarding passive recharge credits and the minimum index levels, which will be discussed later in this report.

City of Wichita ASR Permit Modification Proposal:

The City submitted to the Chief Engineer a proposal titled "ASR Permit Modification Proposal Revised Minimum Index Levels & Aquifer Maintenance Credits" (Proposal). The Proposal included a cover letter dated March 12, 2018, and also included supporting information. The Proposal requested that the following changes be made to the ASR Phase II approved water permits and also be applied to any pending or future ASR water permits:

(1) Lower the minimum index levels that are used to determine when the City can withdraw groundwater recharge credits, and

(2) Authorize Aquifer Maintenance Credits, which would allow a new type of recharge credit that the City could accumulate during times of limited recharge capacity by diverting water from the Little Arkansas River, treating it, and pumping it directly to the City for municipal use instead of physically recharging the Aquifer.

Analysis of Proposal

Lowering of the Minimum Index Levels

The City's Proposal advises that the minimum index levels should be lowered so that the City can withdraw the accumulated recharge credits during an extended drought. The drought and groundwater model submitted with the Proposal indicates that the groundwater levels in a modeled 1% drought will drop below the established minimum index levels in 17 of the 38 Index Cells. The proposed revised lowered minimum index levels also included a contingency between approximately 10 feet and 23 feet that was subtracted from either the existing minimum index levels or the modeled minimum drought water level (generally whichever was lowest). It should be noted that it appears that math errors occur in Table 2-10 (Page 2-24) of the Proposal, most notably for Index Cells Nos. 1 & 2, as the Proposed Levels do not accurately represent the current minimum index levels minus the proposed contingency. The proposed minimum index levels result in a lowering of the established minimum index levels between approximately nine and 23 feet, depending on the Index Cell.

The ASR Phase I and Phase II Orders both prohibit withdrawal of recharge credits if the water level is below the minimum index level in the Index Cell(s). The Chief Engineer concluded in the August 8, 2005, ASR Initial Order that the public interest was protected if the recharge credits could not be withdrawn when the water level was below the currently established minimum index levels. This conclusion was incorporated as conditions to both the August 8, 2005, ASR Phase I Initial Order and the September 18, 2009 ASR Phase II Order signed by the Chief Engineer. The ASR recharge credit withdrawal water permits also include a condition allowing recovery of recharge credits only when the static water level is above the currently established minimum index water level.

Although the City did not file change applications with the Chief Engineer pursuant to KSA 82a-708b because it concluded that the proposed change to the minimum index levels is not one of the changes to a water right specified in KSA 82a-708b, it is appropriate to apply the same standards found in KSA 82a-708b to this proposal. KSA 82a-708b requires that the proposed change be reviewed and either approved or denied in the same manner that a new water permit application is processed, which is done pursuant to KSA 82a-708a, KSA 82a-709 through KSA 82a-714, and the rules and regulations promulgated pursuant to these statutes. Pursuant to these statutes and rules and regulations, it is the burden of the applicant, among other requirements, to show that the change will not impair existing water rights and will not prejudicially and unreasonably affect the public interest.

Since the Chief Engineer concluded that the public interest was protected by not allowing recharge credits to be withdrawn when the static water level was below the current minimum index level, then it is the burden of the City to demonstrate to the Chief Engineer that the proposed lowered minimum index levels still protects the public interest. Additionally, it is the burden of the applicant to show that the change will not impair existing water rights. It is also the burden of the applicant that the change will not cause the unreasonable raising and lowering of the static water level. The Proposal contains none of these requirements.

Additionally, the subject of minimum desirable streamflow (MDS) was not addressed in the Proposal. The City's ASR Project groundwater recharge credits withdrawal water permits are subject to minimum desirable streamflow requirements pursuant to KSA 82a-703c. The Proposal does include any information on how MDS of the Little Arkansas River and the Big Arkansas River will be affected by allowing recharge credits to be withdrawn at the proposed lower minimum index level. Most certainly MDS would be negatively impacted by the Proposal and this should be further evaluated. Indeed, adversely affecting MDS would be considered an unreasonable lowering of the static water level.

Also, the potential adverse impact to groundwater quality by the increased migration, both of the Burrton chloride plume and the saline groundwater in the vicinity of the Big Arkansas River in the southern portion of the Basin Storage Area, was not addressed in the Proposal. Certainly, the lowering of the minimum index levels and allowing the City to pump the aquifer below the current minimum index levels will increase the hydraulic gradient and increase the migration of the salt contamination.

Finally, pursuant to the ASR Phase II MOU between the District and the City, and signed on December 3, 2008, the District has granted spacing waivers based on the current minimum index levels and the City's guarantee that recharge credits would not be withdrawn if the water level was below the currently established minimum index levels. The City, in their Commitment to MOU Issue No. 6 regarding an ASR Project recharge and recovery well being located closer than the minimum spacing requirement of 660 feet to an existing domestic water well(s), specifically states, "Because the Project recharge and recovery wells can only be pumped if water levels in the aquifer are higher than the historic low level, no impairment is expected." Therefore, the proposed lowering of the minimum index levels is inconsistent with the ASR Phase II MOU.

Aquifer Maintenance Credits

The City proposes to create a new type of recharge credit - Aquifer Maintenance Credits (AMCs), which would allow a new type of recharge credit that the City could accumulate during times of limited recharge capacity by diverting water from the Little Arkansas River, treating it, and pumping it directly to the City for municipal use instead of physically recharging it.

There are several regulations and definitions in the DWR and District Rules and Regulations that were established when the City's ASR Project was first being considered and permitted. These include, but are not limited to:

The Aquifer Storage and Recovery Permitting Regulation K.A.R. 5-12-1(a) states that: "An operator may store water in an aquifer storage and recovery system under a permit to appropriate water for artificial recharge if the water appropriated is source water."

"Aquifer storage and recovery system" as defined by District Rule and Regulation K.A.R. 5-22-1(d) and by DWR Rule and Regulation K.A.R. 5-1-1(f) "means a physical infrastructure that meets the following conditions:

(1) Is constructed and operated for artificial recharge, storage, and recovery of source water; and

(2) consists of apparatus for diversion, treatment, recharge, storage, extraction, and distribution."

"Artificial Recharge" as defined by District Rule and Regulation K.A.R. 5-22-1(f) and DWR Rule and Regulation K.A.R. 5-1-1(g) "means the use of source water to artificially replenish the water supply of the aquifer."

"Aquifer storage" as defined by District Rule and Regulation K.A.R. 5-22-1(c) and DWR Rule and Regulation K.A.R. 5-1-1(e) "means the act of storing water in the unsaturated portion of an aquifer by artificial recharge for subsequent diversion and beneficial use."

"Recharge Credit" as defined by District Rule and Regulation K.A.R. 5-22-1(ee) and DWR Rule and Regulations K.A.R. 5-1-1(mmm) "means the quantity of water that is stored in a basin storage area and that is available for subsequent appropriation for beneficial use by an operator of the aquifer storage and recovery system."

"Source Water" as defined by DWR Rule and Regulation KA.R. 5-1-1(yyy) "means water used for artificial recharge that meets the following conditions:

(1) Is available for appropriation for beneficial use;

(2) is above-base flow stage in the stream;

(3) is not needed to satisfy minimum desirable streamflow requirements; and

(4) will not degrade the ambient groundwater quality in the basin storage area."

In both the August 8, 2005 ASR Phase I Initial Order, and the September 18, 2009 Order approving ASR Phase II, the Chief Engineer expressly prohibited passive recharge credits. The Chief Engineer concluded in the August 8, 2005 ASR Phase I Initial Order, "That passive recharge credits should not be allowed because they are not 'artificial recharge' as defined in K.A.R. 5-1-1, because no source water is being artificially recharged to create those credits". Although "passive recharge credits" is not defined in statute or regulation, the August 8, 2005 ASR Phase I Initial Order provides insight on what "passive recharge" and "passive recharge credits" means relative to the ASR Project. In Finding No. 10 of the ASR Phase I Initial Order, "passive recharge" is stated as being "...water which the City could have legally pumped, but did not pump." In Finding No. 42, "passive recharge credits" is stated as being "...credits for not pumping City wells in the basin storage area..." The City is proposing to receive recharge credits (AMCs) by offsetting pumping of the City's existing groundwater water rights in the Equus Beds Aquifer with surface water diverted from the Little Arkansas River, treated, and sent to the City for municipal use. The City acknowledges this on page 1-2 of the Proposal when the City states: "The water left in storage as a result of utilizing Little Arkansas River flows rather than groundwater from the EBWF would be considered as an ASR Aquifer Maintenance Credit (AMC) with similar characteristics to the current ASR recharge credits. Clearly, AMCs are passive recharge credits and expressly prohibited by the ASR Phase I and Phase II Orders of the Chief Engineer.

The current Chief Engineer in a June 1, 2018, letter to the District and the City advised that "Based on our ASR regulations and the ability to modify Wichita's existing project and accounting system, it is our opinion that, with the inclusion of proper terms and conditions and limitations, an accounting method which creates the functional equivalence of aquifer recharge could be implemented." The letter and the included answers to some of the District's questions (that were sent to the Chief Engineer by letter dated April 27, 2018), goes on to use the terms "functional equivalence", "functionally equivalent", and "functional equivalent" five times regarding aquifer recharge and recharge credit accounting.

Changing the accounting procedures would require a change to statutes and/or rules and regulations and the City has not made this request. K.A.R. 5-1-1(mmm) and K.A.R. 5-22-1(ee) both specify that a recharge credit is derived from water put into a basin storage area and "available for subsequent appropriation." The water must actually be injected into the aquifer for subsequent later use. It is my expert opinion that this is not a "gray area" that can be over-ridden by a term such as "functional equivalent". It is clear that physical source water must be injected into the aquifer in order to accumulate a recharge credit.

AMC accumulation does not include "artificial recharge," as defined by K.A.R. 5-1-1(g) and K.A.R. 5-22-1(f), as no source water will be artificially recharged when AMCs are accumulated. The Aquifer Storage and Recovery Accounting Regulation K.A.R. 5-12-2(b) specifies the items that must be included in determining the amount of recharge credits accumulated. These items include artificial recharge. AMCs are not "artificial recharge" and, in fact, AMCs are not identified in K.A.R. 5-12-2. In both the August 8, 2005 Initial Order approving ASR Phase I, and the September 18, 2009 Order approving ASR Phase II, the Chief Engineer found "That aquifer storage and recovery means the artificial recharge, storage and recovery of water and consists of apparatus for diversion, treatment, recharge, storage, extraction and distribution of water." K.A.R. 5-1-1(f) and K.A.R. 5-22-1(d) both define "aquifer storage and recovery system" in similar terms and both include "artificial recharge" as a key component. Under the AMC proposal, there is no artificial recharge, as the treated surface water is sent to the City for municipal use rather than being injected into the aquifer. Therefore, the AMC proposal is not merely a modification of the applicable accounting procedures for Phase II of the ASR Project. Rather, AMCs are a fundamental change in the way recharge credits can be accumulated and AMCs are not found anywhere in Kansas statutes or regulations. In fact, AMCs are counter to the existing ASR regulations, which clearly require physical source water to be injected into the aquifer to be able to accumulate recharge credits.

Furthermore, the existing ASR Phase II recharge and recovery water permits, for which the City is requesting be modified to allow the accumulation of AMCs, were previously exempt from GMD2 Safe Yield Regulation K.A.R 5-22-7(a) pursuant to K.A.R. 5-22-7(b)(7), which exempts an application for an aquifer storage and recovery well. However, because there is no artificial recharge and therefore no storage with the AMC proposal, the existing and any future ASR Phase II water permit applications would be subject to the District's Safe Yield Regulation K.A.R. 5-22-7(a). Based on safe yield evaluations conducted previously by the District, there is no groundwater available for appropriation in the City's Equus Beds Aquifer well field area and therefore new groundwater appropriations cannot be approved, except for recovery of recharge credits established as a result of physical artificial recharge. AMCs would allow appropriation of groundwater where there is no groundwater available for appropriation. This is not in the public interest as described in K.A.R. 5-3-9 (b), which states that it is in the public interest that only the safe yield of a source supply be appropriated. Clearly, allowing accumulation of AMCs is appropriation of additional groundwater in excess of the safe yield of the source of supply. AMCs would not only further over-appropriate the source of supply in the City's Equus Beds Aquifer well field area, but would also be a takings of the prior water right holders in the area, as their source of supply would be appropriated by another junior water right(s). The City's proposal would allow the City to appropriate

120,000 acre-feet of groundwater in an area that the source of supply for the proposed AMCs is already fully dedicated to existing senior water rights, based on safe yield calculations. Thus, no water can be credited to provide additional appropriation without first adding additional water to the supply with physical artificial recharge. To do so would be taking prior water rights' groundwater storage and groundwater that is already dedicated to prior water rights.

Additionally, AMCs are a different source of water for which no definition exists in Kansas statutes or regulations, unlike "groundwater", "surface water", and "recharge credits" which are all defined in K.A.R. 5-1-1. The AMC proposal requests that the source of supply of the aquifer storage and recovery water permits (both existing and future ASR Phase II permits) be changed to allow AMCs to be accumulated and become a source of supply under the auspice of a "recharge credit". However, AMCs are not "recharge credits", as no artificial recharge occurs and no source water is stored to establish the recharge credit. Clearly, a basic tenet of Kansas water law is that the source of supply of a water right cannot be changed and any modifications to existing water rights must relate to the same local source of supply. In fact, the Chief Engineer's Order to Modify Hearing and Schedule dated September 27, 2018, states that the proposed changes must relate to the same local source of supply. Since AMCs are a different, albeit undefined source of supply, the accumulation of AMCs cannot be approved.

Finally, Water Permit No. 46,627 is the surface source water permit for ASR Phase II and was approved by the Chief Engineer on September 18, 2009, for 45,230 acre-feet per year at 41,667 gallons per minute from a surface intake on the Little Arkansas River. The authorized beneficial use is for both Artificial Recharge in the Basin Storage Area and Municipal use by the City of Wichita, *et al.* Water Permit No. 46,627 does not authorize AMCs as a beneficial use, as AMCs are not Artificial Recharge or Municipal use. However, if the accumulation of AMCs is approved, the City would divert surface water from the Little Arkansas River, treat it, and pump it to the City for municipal use, which is clearly already allowed. However, at the same time the treated surface water was being used for municipal use, the same surface water would be counted as a recharge credit (minus any initial loss). It is impossible for the same water to be used at the same time for two different uses – in this case, for municipal use and for the accumulation of recharge credits.

Conclusions

1. The proposed lowering of the minimum index levels, thereby allowing the City to withdraw recharge credits when the water level is at a lower level in the Basin Storage Area and most likely the Equus Beds Aquifer is under stress from drought conditions, erodes the protection to senior groundwater users in the area.
2. The impact caused by lowering the minimum index levels to existing groundwater users in the Basin Storage Area and the impact to the minimum

desirable streamflow in the Little Arkansas River and Big Arkansas River has not been properly evaluated.

3. It is the burden of the City to demonstrate to the Chief Engineer that the proposed lowered minimum index levels will not prejudicially and unreasonably affect the public interest, will not impair existing water rights, and will not cause the unreasonable raising and lowering of the static water level. The Proposal contains none of these requirements.
4. The proposed lowering of the minimum index levels is inconsistent with the ASR Phase II MOU between the District and the City, as the District has granted spacing waivers based on the current minimum index levels and the City's guarantee that recharge credits would not be withdrawn if the water level was below the currently established minimum index levels.
5. Passive recharge credits are expressly prohibited by the ASR Phase I Initial Order issued by Chief Engineer David Pope and the ASR Phase II Order issued by Chief Engineer David Barfield.
6. The August 8, 2005 ASR Phase I Initial Order provides insight on what "passive recharge" and "passive recharge credits" means relative to the ASR Project. In Finding No. 10 of the ASR Phase I Initial Order, "passive recharge" is stated as being "...water which the City could have legally pumped, but did not pump." In Finding No. 42, "passive recharge credits" is stated as being "...credits for not pumping City wells in the basin storage area...". Therefore, the proposed Aquifer Maintenance Credits are "passive recharge credits", because there is no active physical artificial recharge occurring when AMCs would be accumulated. Additionally, the City would be receiving credit for offsetting groundwater the City could have pumped in the Basin Storage Area under the authority of the City's existing native water rights authorized by Vested Right HV006, and Water Rights No. 388 and 1006, with surface water from the Little Arkansas River.
7. The proposed Aquifer Maintenance Credits are not consistent with, and not allowed by, the Kansas Water Appropriation Act (KWAA) and the Rules and Regulations promulgated under the KWAA.
8. The proposed accumulation of AMC's does not meet the definition of "Source Water" found in K.A.R. 5-1-1(yyy), as the source water from the Little Arkansas River is not being used for artificial recharge when AMCs would be accumulated; rather the source water is being used for municipal use.
9. The proposed accumulation of AMCs does not meet the definition of "Artificial Recharge" found in K.A.R. 5-22-1(f) and K.A.R. 5-1-1(g), as the source water from the Little Arkansas River is not being used to artificially replenish the water supply of the aquifer; rather the source water is being used for municipal use.
10. The proposed accumulation of AMC's does not meet the definition of "Aquifer Storage" found in K.A.R. 5-22-1(c) and K.A.R. 5-1-1(e), as the source water from the Little Arkansas River is not being stored in the unsaturated portion of

the Equus Beds Aquifer by artificial recharge; rather it is being used for municipal use.

11. AMCs are a different source of water for which no definition exists in Kansas statutes or regulations, unlike "groundwater", "surface water", and "recharge credits" which are all defined in K.A.R. 5-1-1.

12. The proposed accumulation of AMCs cannot be considered to be "functionally equivalent" to physical recharge credits because the applicable laws, regulations, and the ASR Phase I and Phase II Orders of the Chief Engineer clearly do not allow this type of recharge credit.

13. In my opinion and based on my experience and expertise, both the lowering of the minimum index levels and allowing the accumulation of AMCs, will adversely impact the aquifer and other groundwater users in the Basin Storage Area, will increase the migration of saltwater contamination in the Burrton and Big Arkansas River areas, and will negatively affect minimum desirable streamflow in the Little Arkansas River and the Big Arkansas River.

14. The City of Wichita ASR Permit Modification Proposal as submitted to the Chief Engineer on March 12, 2018, should not be approved.

Documents and References reviewed and used for this report

1. The City of Wichita ASR Permit Modification Proposal and accompanying letter dated March 12, 2018, and supporting documentation.
2. Documents posted to the DWR ASR webpage at the following: https://www.agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/aquifer-storage-and-recovery/wichita-asr
3. The Kansas Water Appropriation Act, K.S.A 82a-701 et seq.
4. DWR and District Rules and Regulations promulgated pursuant to the Kansas Water Appropriations Act.
5. The Kansas Groundwater Management District Act, K.S.A 82a-1020 et seq.
6. Memorandum of Understanding between Equus Beds Groundwater Management District No. 2 and the City of Wichita, effective September 9, 2004.
7. ASR Phase I Initial Order issued by the Chief Engineer on August 8, 2005.
8. Memorandum of Understanding between Equus Beds Groundwater Management District No. 2 and the City of Wichita, effective December 3, 2008.
9. ASR Phase II Order issued by the Chief Engineer on September 18, 2009.
10. The City's approved ASR water permits.
11. All documents exchanged in discovery in this Administrative Hearing.
12. Any other documents incidental to the above documents.

This report is true and correct to the best of my knowledge.

February 18, 2019

Tim Boese

Tim Boese, Manager
Equus Beds Groundwater
Management District No. 2
313 Spruce Street
Halstead, KS 67056
(316) 835-2225

CV for Tim Boese:

Work Experience:
1992 – Present: Equus Beds Groundwater Management District No. 2.

1. Hydrologic Technician: 1992 – 2005
2. Hydrologist: 2005 -2007, including Interim Manager for parts of 2006 & 2007
3. Manager: November 2007 to present

Education:
Bachelor of General Studies – Fort Hays State University

Experience, knowledge, and expertise in: Equus Beds Aquifer, groundwater management, and Kansas water rights, laws, and regulations.

Additional:
Serve / Served on the following committees & associations:

1. Kansas Corporation Commission Oil & Gas Advisory Committee
2. NRCS Kansas Technical Committee
3. City of Wichita Water Utilities Advisory Committee
4. Sedgwick County Stormwater Technical Advisory Committee
5. Kansas Geological Survey Advisory Council
6. Kansas Groundwater Management Districts Association (KGMDA)
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In the Matter of the City of Wichita's	)	
Phase II Aquifer Storage and Recovery Project	)	Case No. 18 WATER 14014
In Harvey and Sedgwick Counties, Kansas.	)	
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Pursuant to K.S.A 82a-1901 and K.A.R. 5-14-3a.

Expert Report of Masih Akhbari, PhD, PE

1. I am Masih Akhbari. I am a Project Engineer at Larry Walker Associates (LWA) and a Visiting Scholar at Colorado Water Institute, an affiliate of Colorado State University. Starting in 2018, LWA has been leading consultant teams to develop Groundwater Sustainability Plans in compliance with California's Sustainable Groundwater Management Act. I am an active member of the team supporting these projects. I am also in the process of founding Global Water Resources Solutions Inc. with the mission to provide practical solutions for water resources and environmental problems. My physical address is 529 Washington Ave., Unit #4, Santa Monica, CA 90403.

Assignment

2. I have been retained by the office of Adrian & Pankratz, P.A. on behalf of the Equus Beds Groundwater Management District #2, with an hourly rate of $150, to review the documentations on the development of the USGS Equus Beds Groundwater Flow Model (EBGWM), the Wichita City's (the City's) Aquifer Storage and Recovery (ASR) permit modification proposal, and also review and evaluate the performance of the Drought Model, developed by Burns & McDonnell by modifying the EBGWM. I understand that the Drought Model simulates the total combined effects of a 1% drought on the local and regional water levels surrounding the City's ASR project. I have been asked to analyze the model's suitability to be used as a tool to identify revised Minimum Index Levels in the City's ASR Permit.

Summary of Opinions

3. My overall opinion in this matter is that while the EBGWM can follow the overall trend of groundwater level changes across the aquifer, its simulation results are not accurate enough to propose modified ASR Minimum Index Levels. Overall, the model tends to underestimate groundwater levels. Even in 60% of the monitoring wells that the USGS report has selected to show the accuracy of simulated results, groundwater levels are underestimated. The underestimations are prevalent specially during drought periods. However, minimum drought model elevations have been considered to propose modified ASR Minimum Index Levels for over half of the Index Wells. Additionally, while the USGS report explicitly mentions that this model is not suitable for simulating water-level drawdown near a single well, water level elevations at the location of the Index Wells have been used as the basis to propose modified ASR Minimum Index Levels for over half of the Index Wells.

Qualifications

4. I hold an M.S. degree in Environmental Engineering and a Ph.D. in Hydrology and Water Resources Management. I am also registered as a Professional Engineer in the State of Colorado. For both my M.S. and Ph.D. research, I developed computer simulation models to support water resources decision-making and management. My Ph.D. was followed by a postdoctoral research at the Center for Watershed Sciences, University of California Davis, where I developed highly complicated integrated computer simulation models for water resources planning and decision-making.
5. In 2015, I joined Riverside Technology inc. (acquired by RTI International as its Water Resources Division in 2017) as a Senior Water Resources Engineer. The Division of Water

Resources of RTI International is a cutting-edge entity that provides innovative IT-based solutions to develop decision support systems for water resources planning and management. In Summer 2018, I joined Larry Walker Associates to assist the company in leading consultant teams to develop Groundwater Sustainability Plans in compliance with California's Sustainable Groundwater Management Act.

6. I am a co-author of the book "*Groundwater Hydrology: Engineering, Planning, and Management*," published by CRC Press in 2011. This book presents state-of-the-art subjects and techniques in the education and practice of groundwater, discusses groundwater hydrology, presents technical aspects of developing and solving groundwater flow equations, introduces conceptual models to simulate groundwater systems, and examines details of groundwater flow modeling. I am currently working on the second edition of the book, which will be released in late 2019, to add topics such as Managed Aquifer Recharge, Best Management Practices in Sustainable Management of Groundwater, and facilitating negotiations over groundwater resources management.
7. I have also co-advised multiple graduate students with two of them having focused their thesis on groundwater management. These theses are titled: "*Agent-based Modeling for Sustainable Groundwater Management in Ardabil Plain*" and "*Developing a multi-agent model to optimize the qualitative-quantitative management of groundwater for agricultural, industrial and municipal purposes*."
8. Additionally, I have served as review panelist for the 2017 National Science Foundation Graduate Research Fellowship Program, as a session chair and convener at the 2015 American Geophysical Union Fall Meeting, as a reviewer for multiple scientific journals, and provided other services as demonstrated in my CV.

Documents Reviewed

9. As part of my assignment, I have reviewed the USGS report on the EBGWM development and calibration process, titled: "Simulation of Groundwater Flow, Effects of Artificial Recharge, and Storage Volume Changes in the Equus Beds Aquifer near the City of Wichita, Kansas Well Field, 1935–2008," the ASR permit modification proposal, developed by Burns and McDonnel, titled: "ASR Permit Modification Proposal Revised Minimum Index Levels & Aquifer Maintenance Credits," as well as its relevant associated appendices. I have also reviewed the performance of the Drought Model as well as Model Run No. 3, developed by Burns and McDonnel.

My Evaluations

10. I initiated my evaluation process by reviewing the USGS report on the EBGWM development to understand and assess the model's structure, initial and boundary conditions, suitability of data imported to the model as input files, the model's calibration process, and observed data used to calibrate the model. When needed, I also downloaded and reviewed tables attached to this report as listed on Page 89 of the report.

11. Additionally, I reviewed the ASR Permit Modification Proposal, developed by Burns & McDonnel, and its attachments to understand and evaluate the process and data used to reconstruct the 1% Drought, the logic used to propose the modified Minimum Index Levels, and scenarios defined to create ASR accounting simulations.

12. After careful review of these reports, I started evaluating the Drought Model by spot checking to verify if the model correctly reads the imported data for the following parameters: evapotranspiration, recharge rates, hydraulic conductivity, well pumping rates,

layer thickness, specific yield and specific storage, initial heads, top and bottom elevations of each layer.

13. As an important test to confirm the model performance, I calculated water balance within the Basin Storage Area (BSA) in Model Run No. 3, described in Attachment J of the ASR Permit Modification Proposal, as a representative of the Drought Model. I performed this test using Groundwater Vistas, which is a pre- and post-processing software package for importing input files and analyzing model results. This test does not assess whether the model is accurately simulating the system. It does help verify, however, whether there is a reasonable balance among the inflows, outflows, and storage rate within each of the model cells.
14. To evaluate water level changes resulted from the 8-year drought and the 2-year recovery periods, I ran the original form of the Drought Model, which has 1998 water levels data as its initial heads. I also updated the initial heads using the 2001 data and re-ran the Drought Model to evaluate the model's response to the updated initial heads. The average of 2001 initial heads over the location of the 38 index wells is about 11.85 ft higher than the original heads introduced to the model (from 1998). **Table 1** at the end of this report presents the *differences* between the 2001 and 1998 initial heads, as well as the resulted water table elevations (ft) during the 8-year drought and 2-year recovery periods. **Table 2** also shows initial heads and water table elevations during these periods at the location of the index wells.
15. **Figure 1** at the end of this report also depicts annual water level changes within the BSA resulted from both initial heads before, during, and after the 8-year drought as well as after the2-year recovery period.

Evaluation Results

16. Evaluating the Drought Model, I could verify that the model reads all input data correctly, the model's water balance error averaged over the BSA is below 1%, verifying model performance within the model cells. Both the original form of the Drought Model and the model updated with 2001 initial heads respond reasonably to the drought and recovery periods as illustrated in **Figure 1** and **Figure 2**. However, reviewing the documents and the Drought Model, there are some concerns associated with the model results that make the suitability of these results to propose modified ASR Minimum Index Levels questionable. These concerns are explained in the following.
17. As presented in **Table 2** and illustrated in **Figure 2**, when initial water heads are updated with the 2001 data, which is on average 11.85 ft higher than the original heads, and all other boundary and initial conditions are kept unchanged, there is a steep drop in water level within the first year (from Stress Period 0 to Stress Period 1). This drop is significantly more substantial in the index wells closer to the east side of the BSA, where the water is drained rapidly into the Little Arkansas River, e.g. Index Well # 12. While this steep drop verifies the model performance, it emphasizes on the model sensitivity to boundary and initial conditions and highlights the importance of setting these conditions accurately. Inaccurate setting of these conditions may result in unwanted drainage or recharge of large quantities of water out of or into the aquifer.
18. The USGS report uses Root Mean Square (RMS) error as the metric to evaluate model calibration. RMS error is a measure to take an average of the differences between the observed and simulated data values over time and space in this case. To elaborate, when and where observed data have been available, the difference between the observed and simulated

values has been calculated and squared. Then, these squared differences for all timesteps with observed data and at all monitoring wells have been averaged and the root of this value has been calculated as the RMS error. Clearly, such average offsets the highly over- or under-estimated simulation values by balancing them out with when or where the errors is low. According to the USGS report, the RMS error for water-levels of the transient calibration of the EBGWM is 2.48 ft, indicating "the acceptability of the calibrated model," as stated in Page 48 of the USGS report. However, more detailed comparison between simulated and observed values indicates that the model tends to mainly underestimate water levels across the 20 selected monitoring wells shown in Figure 34 of the USGS report. I provided a copy of this figure at the end of this report (**Figure 3**).

19. **Figure 4** provides a copy of Figure 40 of the USGS report, illustrating simulated versus observed groundwater levels in the selected monitoring wells. As depicted in this figure, the model tends to underestimate groundwater levels in the majority of these monitoring wells. For further analysis of these graphs, I downloaded the simulated and observed water levels in selected monitoring wells from Table 9 of the USGS report, listed on Page 89 of this report, and provided a summary of my analysis in **Table 3**. According to this table:

    a. While the RMS error seems to be low, comparing the total range of water level changes over the entire observation period (Column C) with the maximum and average differences between observed and simulated values (Columns D and E, respectively) suggests that the error should be taken into account more seriously. For example, at monitoring well #741, water levels fluctuate about 8.21 ft over the period of 1952 to 2008 (Column B). The maximum and average differences between the simulated and observed water levels are 4.95 ft and 3.03 ft, respectively, which correspond to 60% and 37% of the total range of long-term water level fluctuations (Columns F and G, respectively). The averages of these ratios, presented in Columns E and F, over all 20 wells are 68% and 31%, respectively.

b. As exhibited in Column H simulated water levels are underestimated in 60% of these monitoring wells.

c. Simulated data appropriately follows the trend of the observed data in 75% of the wells (Column I).

20. Page 53 of the USGS report states that "*Cumulative streamflow gain and loss observations are similar to the cumulative simulated equivalents and are shown for the Arkansas River and Little Arkansas River in figure 41*". While simulated cumulative streamflow gains and losses in the Arkansas River show a good match with the observed data, based on Figure 41 of this report, these cumulative simulations for the Little Arkansas River overestimate observations by approximately 17%. A copy of this figure is provided at the end of this report (**Figure 5**).

21. The last paragraph in Page 72 of the USGS report states that "*The change in storage between AR and NAR simulations for 2007 was 1,107 acre-ft and metered recharge was 963 acre-ft for the total model area. For 2008 the simulated change in storage was 684 acre-ft and metered recharge was 833 acre-ft. Total simulated change in storage was 1,790 acre-ft and total metered recharge was 1,796 acre-ft*". This translates into an approximately 15% overestimation of storage in 2007 and about 18% underestimation of storage in 2008. While comparing the combined 2007 and 2008 storage values for simulated results with observed data offsets the relatively large errors, it might not always be the case; i.e. the consecutive

years may have a cumulative effect instead of offsetting effect. Therefore, much longer comparison of observed versus simulated storage data is required to draw the conclusion that such error could be neglectable.

22. Item 2 in the Model Limitations Section of the USGS report (Page 72) explicitly states that "*The groundwater-flow model was discretized using a grid with cells measuring 400 ft by 400 ft. Model results were evaluated on a relatively large scale and* ***cannot be used for detailed analyses such as simulating water-level drawdown near a single well****. A grid with smaller cells would be needed for such detailed analysis*." However, as presented in Table 2-10 of the ASR Permit Modification Proposal, minimum Drought Model elevations at the location of Index Wells have been used to propose modified ASR Minimum Index Levels for more than half of these wells. A copy of this table is provided at the end of this report (**Table 4**).

23. Page 2-11 of the ASR Permit Modification Proposal states that "*To select initial head conditions for the 1% drought scenario, the simulated transient water levels provided by USGS in the original model report for 1990-2008 were compared against the designed recharge capacity of existing ASR infrastructure. This comparison indicated that the simulated groundwater levels representing the end of the 1998 period were the best match for representing the minimum groundwater levels required to maintain 30 MGD of physical ASR recharge capacity*." However, it is not clear why minimum groundwater levels required to maintain 30 MGD of physical ASR recharge capacity should be the basis to calculate the modified Minimum Index Levels.

Conclusions

24. I reviewed the development documentation of the USGS EBGWM, the City's ASR permit modification proposal, and the performance of the Drought Model. I performed the review and draw my conclusions based on my experience in the field as a researcher studying prevailing literature, modeler, co-advisor, and co-author of a textbook titled "Groundwater Hydrology: Engineering, Planning, and Management." Based on my review, the USGS EBGWM structure is correct and mass balance equations within the model cells are solved appropriately resulting in a less than 1% error in mass balance within the BSA area. This means that within the model, calculating the balance among inflows, outflows, and storage change in each model cell and averaging these over all model cells within the BSA results in a less than 1% error. While this confirms the model performance, it does not mean that the model is accurately simulating groundwater levels. To draw such conclusion, model results should be compared with observed data.
25. Page 2-7 of the ASR Permit Modification Proposal claims that "*The EBGWM is currently the best forward analysis and prediction tool available for simulating the total combined effects of a 1% drought on the local and regional water levels surrounding the City's ASR project*." However, this does not mean that the model simulation results are accurate enough to propose modified ASR Minimum Index Levels. The EBGWM might be the best analysis tool currently available to estimate the overall trend of groundwater level fluctuations across the aquifer, but not to accurately estimate groundwater levels at specific well locations. This can be partially due to the large special scale of the modeling area and large grids cells constructed in the model.

26. The model tends to underestimate groundwater levels in 60% of the monitoring wells selected by USGS to show the acceptability of model results. The underestimations are prevalent specially during drought periods. However, minimum drought model elevations have been considered to propose modified ASR Minimum Index Levels for over half of the Index Wells.

27. The average difference between simulated and observed data could account for about 31% of the difference between minimum and maximum groundwater levels within all the 20 selected monitoring wells during the entire period with available observation data (as explained in Paragraph 19.a). For example, at well # 741 water levels fluctuate about 8.21 ft over a period of 56 years and the average difference between the simulated and observed water levels is 3.03 ft, meaning that the model error accounts for over 30% of the total long-term water fluctuations in this well. This value could be as high as 68% averaged over all these wells.

28. The USGS report explicitly mentions that this model is not suitable for simulating water level drawdown near a single well. However, water level elevations at the location of the Index Wells have been used as the basis to propose modified ASR Minimum Index Levels for over half of the Index Wells.

Dated: February 15, 2019

M. Akhbari

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Table 1 Differences between 1998 and 2001 initial heads, water table elevations during the 8-year drought and 2-year recovery periods at the location of the Index Wells (ft)

Index Well #	Initial Head	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5	End of Year 6	End of Year 7	End of Year 8	End of Year 9	End of Year 10
1	6.4	8.1	7.7	6.7	5.5	4.6	3.9	3.3	2.8	2.5	2.1
2	19.7	12.6	10.1	8.3	6.9	5.8	4.9	4	3.5	3	2.6
3	16.8	5.6	3.9	3	2.4	1.9	1.6	1.3	1.1	1	0.8
4	10.6	7.2	7	6.6	6.2	5.8	5.3	4.7	4.3	3.8	3.4
5	16.2	13.1	12	10.6	9.2	8	6.9	6	5.1	4.5	4
6	27.5	18.1	12.8	9.7	7.6	6.2	5	4.2	3.5	2.9	2.4
7	27.7	14.9	10.4	7.7	6.1	4.8	4	3.3	2.8	2.4	2
8	4.4	5.2	5.1	5.1	4.9	4.8	4.5	4.2	3.8	3.4	3.1
9	18.6	15	13.4	11.8	10.3	8.9	7.8	6.7	5.9	5.1	4.5
10	32.4	22.8	17.3	13.6	11	9.1	7.5	6.3	5.4	4.6	3.9
11	25.7	16	11.5	8.8	6.9	5.6	4.6	3.9	3.2	2.8	2.4
12	8.2	0.9	0.6	0.3	0.3	0.2	0.2	0.1	0.1	0.2	0.1
13	5.7	2.5	2.5	2.8	2.8	2.8	2.8	2.5	2.3	2.1	1.7
14	14.5	10.6	9.2	8.2	7.1	6.3	5.4	4.9	4.2	3.7	3.2
15	22.4	18.7	15.4	12.8	10.7	9.1	7.8	6.7	5.7	4.8	4.1
16	22.9	20.5	16.4	13.4	11.2	9.4	8	6.7	5.7	4.8	4
17	16.1	6.6	4.6	3.4	2.7	2.1	1.7	1.4	1.2	1	0.8
18	2.4	1.8	1.8	2	2	2	1.9	1.7	1.5	1.3	1
19	5.4	5.6	5.4	4.9	4.3	3.9	3.4	2.9	2.5	2.2	2
20	14	13.3	11.7	10	8.6	7.2	6.3	5.3	4.6	4	3.5
21	21.2	17.8	14.9	12.5	10.5	8.9	7.5	6.3	5.4	4.7	3.9
22	18	10.5	7.3	5.4	4.2	3.4	2.8	2.3	1.9	1.6	1.3
23	12.8	1.5	0.8	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.2
24	0.3	0.5	0.5	0.7	0.7	0.6	0.5	0.5	0.4	0.3	0.3
25	-0.4	1.6	1.9	1.9	1.8	1.6	1.5	1.3	1.2	0.9	0.8
26	8.5	5.8	5.2	4.7	4	3.5	3	2.5	2.1	1.8	1.6
27	13.1	10	8.6	7.1	5.8	4.7	4	3.4	2.8	2.4	2
28	16.1	10.9	7.3	5.3	4	3.3	2.5	2	1.7	1.4	1.2
29	13.8	2.3	1.2	0.8	0.6	0.4	0.3	0.3	0.3	0.2	0.2
30	0.5	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2
31	2.5	1.4	1	0.8	0.6	0.5	0.5	0.4	0.3	0.2	0.2
32	4.8	1.6	0.8	0.5	0.5	0.4	0.3	0.2	0.2	0.2	0.1
33	8.8	1.6	0.7	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1
34	9.5	2.5	1.9	1.7	1.7	1.6	1.7	1.7	1.7	1.9	2
35	-1.3	0.3	0.2	0.4	0.3	0.4	0.3	0.3	0.3	0.2	0.1
36	1.4	0.3	0	0.2	0	0.1	0	0.1	-0.1	-0.2	-0.1
37	1.2	0.4	0.1	0.2	0.1	0.1	0	0	-0.1	-0.1	-0.1
38	5.9	3.7	3.1	3	3	3	2.9	3.1	2.9	3.1	3.1

Table 2 Original (1998 - gray lines) and 2001 (white lines) initial heads as well as water table elevations during the 8-year drought and 2-year recovery periods at the location of the Index Wells (ft)

Index Well #	Initial Head	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5	End of Year 6	End of Year 7	End of Year 8	End of Year 9	End of Year 10
1	1437.8	1436.4	1435.3	1433.9	1433	1432	1431.3	1430.5	1430.1	1431	1432.1
	1444.2	1444.5	1443	1440.6	1438.5	1436.6	1435.2	1433.8	1432.9	1433.5	1434.2
2	1416.3	1414.6	1413.2	1411.8	1410.8	1409.8	1409.1	1408.4	1407.9	1409.1	1410.3
	1436	1427.2	1423.3	1420.1	1417.7	1415.6	1414	1412.4	1411.4	1412.1	1412.9
3	1394.5	1392.5	1391.8	1391.4	1390.9	1390.7	1390.3	1390.2	1390	1391.5	1392.1
	1411.3	1398.1	1395.7	1394.4	1393.3	1392.6	1391.9	1391.5	1391.1	1392.5	1392.9
4	1429.1	1427.8	1426.7	1425.5	1424.5	1423.2	1422.3	1421.3	1420.6	1421	1421.7
	1439.7	1435	1433.7	1432.1	1430.7	1429	1427.6	1426	1424.9	1424.8	1425.1
5	1419.6	1417.1	1415.8	1414.1	1412.9	1411.3	1410.3	1409	1408.4	1409.8	1410.8
	1435.8	1430.2	1427.8	1424.7	1422.1	1419.3	1417.2	1415	1413.5	1414.3	1414.8
6	1389.1	1387.5	1385	1382.3	1381.4	1379.6	1379.7	1379.5	1379.2	1381.8	1383.8
	1416.6	1405.6	1397.8	1392	1389	1385.8	1384.7	1383.7	1382.7	1384.7	1386.2
7	1381.2	1379.3	1377.4	1375.2	1374.1	1372.8	1372.3	1372.3	1372.1	1374.8	1376.7
	1408.9	1394.2	1387.8	1382.9	1380.2	1377.6	1376.3	1375.6	1374.9	1377.2	1378.7
8	1426.1	1424.9	1424	1422.8	1421.8	1420.6	1419.7	1418.7	1418.1	1418.5	1419.3
	1430.5	1430.1	1429.1	1427.9	1426.7	1425.4	1424.2	1422.9	1421.9	1421.9	1422.4
9	1406.4	1405.9	1404.5	1399.2	1399.9	1396.2	1396.5	1395.5	1394.9	1395.7	1397.4
	1425	1420.9	1417.9	1411	1410.2	1405.1	1404.3	1402.2	1400.8	1400.8	1401.9
10	1382.8	1381	1378.2	1374.1	1372.2	1369.5	1368.9	1368.5	1368.2	1372.2	1375.4
	1415.2	1403.8	1395.5	1387.7	1383.2	1378.6	1376.4	1374.8	1373.6	1376.8	1379.3
11	1375.5	1374.1	1371.9	1369.2	1367.6	1365.9	1365.3	1365	1365	1367.2	1369.6
	1401.2	1390.1	1383.4	1378	1374.5	1371.5	1369.9	1368.9	1368.2	1370	1372
12	1371.9	1370.8	1370.5	1370.7	1370.3	1370.5	1370.2	1370.5	1370.2	1371.5	1371.6
	1380.1	1371.7	1371.1	1371	1370.6	1370.7	1370.4	1370.6	1370.3	1371.7	1371.7

Index Well #	Initial Head	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5	End of Year 6	End of Year 7	End of Year 8	End of Year 9	End of Year 10
13	1424.8	1423.2	1422.3	1420.9	1420.2	1419.1	1418.5	1417.8	1417.6	1419.4	1421.2
	1430.5	1425.7	1424.8	1423.7	1423	1421.9	1421.3	1420.3	1419.9	1421.5	1422.9
14	1402.9	1399.3	1397.2	1393.6	1392.5	1390.2	1389.6	1388.8	1388.4	1393.6	1396.7
	1417.4	1409.9	1406.4	1401.8	1399.6	1396.5	1395	1393.7	1392.6	1397.3	1399.9
15	1383.4	1380.7	1377.6	1372.5	1370.6	1367.3	1366.6	1366	1365.7	1370.2	1374
	1405.8	1399.4	1393	1385.3	1381.3	1376.4	1374.4	1372.7	1371.4	1375	1378.1
16	1373.7	1370	1365.9	1360	1358.4	1354.5	1354.6	1354.4	1354.2	1359.3	1363.1
	1396.6	1390.5	1382.3	1373.4	1369.6	1363.9	1362.6	1361.1	1359.9	1364.1	1367.1
17	1368.1	1366.4	1365.6	1364.8	1363.9	1363.4	1362.9	1362.8	1362.7	1364.2	1365
	1384.2	1373	1370.2	1368.2	1366.6	1365.5	1364.6	1364.2	1363.9	1365.2	1365.8
18	1423.7	1422.1	1421.4	1420.3	1419.8	1418.9	1418.6	1418	1418	1419.7	1421.2
	1426.1	1423.9	1423.2	1422.3	1421.8	1420.9	1420.5	1419.7	1419.5	1421	1422.2
19	1406	1404.2	1402.6	1400.6	1399.6	1398.2	1397.6	1397.1	1396.8	1399.1	1401.1
	1411.4	1409.8	1408	1405.5	1403.9	1402.1	1401	1400	1399.3	1401.3	1403.1
20	1387.5	1386.3	1384.3	1380.6	1378.6	1376.3	1375	1374.3	1373.8	1375.5	1378.2
	1401.5	1399.6	1396	1390.6	1387.2	1383.5	1381.3	1379.6	1378.4	1379.5	1381.7
21	1371	1368	1365.5	1359.9	1358.4	1354.7	1354	1353.2	1353	1356.4	1359.5
	1392.2	1385.8	1380.4	1372.4	1368.9	1363.6	1361.5	1359.5	1358.4	1361.1	1363.4
22	1361.8	1360	1358.5	1356.6	1355.4	1354.2	1353.6	1353.4	1353.4	1355.3	1356.9
	1379.8	1370.5	1365.8	1362	1359.6	1357.6	1356.4	1355.7	1355.3	1356.9	1358.2
23	1359.5	1357.4	1357.1	1356.9	1356.7	1356.6	1356.5	1356.6	1356.5	1358.2	1358.4
	1372.3	1358.9	1357.9	1357.4	1357.1	1356.9	1356.8	1356.8	1356.7	1358.4	1358.6
24	1419.3	1418	1417.5	1417.4	1416.9	1417	1416.6	1416.7	1416.4	1417.9	1418.3
	1419.6	1418.5	1418	1418.1	1417.6	1417.6	1417.1	1417.2	1416.8	1418.2	1418.6
25	1408.7	1407.2	1406.3	1405.6	1404.9	1404.5	1404	1403.9	1403.6	1405.5	1406.5
	1408.3	1408.8	1408.2	1407.5	1406.7	1406.1	1405.5	1405.2	1404.8	1406.4	1407.3
26	1390.3	1388.3	1386.6	1384.4	1383.7	1382.2	1382	1381.7	1381.6	1383.6	1385.1
	1398.8	1394.1	1391.8	1389.1	1387.7	1385.7	1385	1384.2	1383.7	1385.4	1386.7

Index Well #	Initial Head	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5	End of Year 6	End of Year 7	End of Year 8	End of Year 9	End of Year 10
27	1374	1373.6	1371.8	1369.2	1367.2	1365.5	1364.5	1364.3	1364.4	1365.8	1367.8
	1387.1	1383.6	1380.4	1376.3	1373	1370.2	1368.5	1367.7	1367.2	1368.2	1369.8
28	1357.3	1356.5	1352.1	1347.3	1346.3	1343.8	1345.5	1346.9	1347.6	1351.3	1353.8
	1373.4	1367.4	1359.4	1352.6	1350.3	1347.1	1348	1348.9	1349.3	1352.7	1355
29	1354.7	1352.5	1351.4	1350.6	1350.6	1350.2	1350.6	1350.8	1350.9	1352.9	1353.4
	1368.5	1354.8	1352.6	1351.4	1351.2	1350.6	1350.9	1351.1	1351.2	1353.1	1353.6
30	1389.7	1388.2	1387.3	1387.2	1386.7	1386.8	1386.5	1386.9	1386.5	1388.2	1388.5
	1390.2	1389.2	1388.2	1388	1387.4	1387.4	1387	1387.3	1386.8	1388.4	1388.7
31	1379.7	1378.2	1377.2	1377.1	1376.5	1376.6	1376.2	1376.7	1376.4	1378.1	1378.5
	1382.2	1379.6	1378.2	1377.9	1377.1	1377.1	1376.7	1377.1	1376.7	1378.3	1378.7
32	1366.9	1365.3	1363.9	1363.5	1363	1363	1363	1363.7	1363.4	1365.4	1366
	1371.7	1366.9	1364.7	1364	1363.5	1363.4	1363.3	1363.9	1363.6	1365.6	1366.1
33	1353.8	1351.6	1350.1	1349.3	1349.4	1349	1349.7	1350.2	1350.1	1352.3	1352.7
	1362.6	1353.2	1350.8	1349.8	1349.8	1349.3	1349.9	1350.3	1350.2	1352.4	1352.8
34	1347.2	1345.4	1345	1344.9	1344.8	1344.8	1344.9	1345.1	1345	1346.5	1346.6
	1356.7	1347.9	1346.9	1346.6	1346.5	1346.4	1346.6	1346.8	1346.7	1348.4	1348.6
35	1376	1375.2	1374.4	1374.9	1374.2	1374.8	1374.2	1374.9	1374.2	1375.7	1375.8
	1374.7	1375.5	1374.6	1375.3	1374.5	1375.2	1374.5	1375.2	1374.5	1375.9	1375.9
36	1365.8	1364.5	1363.6	1363.9	1363.3	1363.8	1363.3	1364	1363.5	1365.2	1365.3
	1367.2	1364.8	1363.6	1364.1	1363.3	1363.9	1363.3	1364.1	1363.4	1365	1365.2
37	1355.7	1354.1	1353.1	1353.2	1352.8	1353.1	1352.9	1353.5	1353.1	1354.9	1355.1
	1356.9	1354.5	1353.2	1353.4	1352.9	1353.2	1352.9	1353.5	1353	1354.8	1355
38	1346.1	1344.1	1343.6	1343.6	1343.4	1343.5	1343.5	1343.7	1343.6	1345.2	1345.4
	1352	1347.8	1346.7	1346.6	1346.4	1346.5	1346.4	1346.8	1346.5	1348.3	1348.5

Table 3 Comparison between simulated and observed water levels in selected monitoring wells (data downloaded from Table 9 in the USGS report, listed on Page 89 of the report)

(A) Monitoring Well #	(B) Observation Period	(C) Difference between minimum and maximum observed values over the Observation Period(ft)	(D) Max difference between observed and simulated values (ft)	(E) Average absolute difference between observed and simulated values (ft)	(F) Ratio of Column D to Column C	(G) Ratio of Column E to Column C	(H) Mostly under- or overestimate
546	1939-1998	6.99	6.67	2.02	95%	29%	U
733	1938-2008	16.17	4.92	1.77	30%	11%	U
741	1952-2008	8.21	4.95	3.03	60%	37%	U
819	1939-2008	3.09	3.02	2.18	98%	71%	U
857	1958-2008	14.11	6.28	2.96	45%	21%	U
868	1952-2008	10.72	5.76	2.11	54%	20%	U
982	1958-2008	9.51	3.72	1.07	39%	11%	O
1037	1952-2008	16.04	3.69	1.78	23%	11%	Even
1038	1939-2008	37.01	8.59	1.98	23%	5%	Even
1053	1939-2008	4.76	4.38	2.49	92%	52%	U
1149	1952-2008	11.75	5.53	2.18	47%	19%	U
1151	1939-2008	26.01	5.33	1.97	20%	8%	O
1155	1939-2008	4.85	2.72	0.97	56%	20%	U
1253	1939-2008	4.90	2.64	0.89	54%	18%	U
1313	1939-2008	6.63	3.25	1.03	49%	16%	O
1355	1952-2008	14.71	5.54	2.10	38%	14%	O
1445	1958-2008	12.89	4.98	2.00	39%	16%	O
1448	1939-2008	4.02	3.87	1.38	96%	34%	O
1525	1939-2008	3.59	8.62	5.02	240%	140%	U
1692	1970-2008	5.31	8.36	3.50	157%	66%	U

Table 4 Copy of Table 2-10 of the ASR Permit Modification Proposal: Development of Proposed ASR Minimum Index Levels

		Minimum Index Level Elevations			
Index Well No.	Minimum Drought Model Elevation (feet)	Existing Level (1993 Level) (feet)	Basis for Proposed Level[1]	Contingency Added (feet)	Proposed Levels[2] (feet)
IW01C	1429.14	1413.42	Existing	20	1390
IW02C	1407.96	1410.52	Existing	10	1390
IW03C	1389.76	1396.93	Modeled	10	1380
IW04C	1420.35	1417.6	Existing	10	1407
IW05C	1408.21	1407.23	Modeled	10	1398
IW06C	1380.42	1388.74	Modeled	10	1370
IW07C	1372.79	1369.95	Existing	10	1360
IW08C	1418.06	1417.56	Modeled	10	1408
IW09C	1394.74	1394.1	Modeled	10	1385
IW10C	1368.08	1375.09	Modeled	10	1358
IW11C	1365.27	1363.75	Existing	10	1354
IW12C	1370.6	1365.78	Existing	10	1355
IW13C	1417.21	1418.27	Modeled	10	1407
IW14C	1386.6	1396.56	Modeled	10	1377
IW15C	1364.07	1369.75	Modeled	10	1354
IW16C	1354.11	1360.21	Modeled	10	1344
IW17C	1363.16	1360.59	Existing	10	1351
IW18C	1417.28	1421.4	Modeled	10	1407
IW19C	1396.07	1398.95	Modeled	10	1386
IW20C	1373.34	1376.05	Modeled	10	1363
IW21C	1352.12	1363.04	Modeled	10	1342
IW22C	1353.79	1354.92	Modeled	10	1344
IW23C	1356.94	1355.55	Existing	10	1345
IW24C	1416.31	1418.96	Modeled	10	1406
IW25C	1403	1407.27	Modeled	10	1393
IW26C	1380.64	1374.89	Existing	10	1364
IW27C	1363.16	1360.92	Existing	10	1350
IW28C	1343.8	1349.14	Modeled	10	1334
IW29C	1350.36	1349.51	Modeled	10	1340
IW30C	1386.13	1379.77	Existing	10	1370
IW31C	1376.18	1366.06	Existing	10	1356
IW32C	1362.86	1356.51	Existing	10	1346
IW33C	1348.93	1344.68	Existing	10	1334
IW34C	1344.62	1344.24	Modeled	10	1335
IW35C	1373.74	1366.76	Existing	10	1356
IW36C	1363.02	1360.13	Existing	10	1350
IW37C	1352.85	1350.51	Existing	10	1340
IW38C	1343.19	1344.65	Modeled	10	1333

[1] Existing refers to the Existing 1993 Level, Modeled refers to the Minimum Drought Model Elevation.
[2] Values were rounded to the nearest foot.

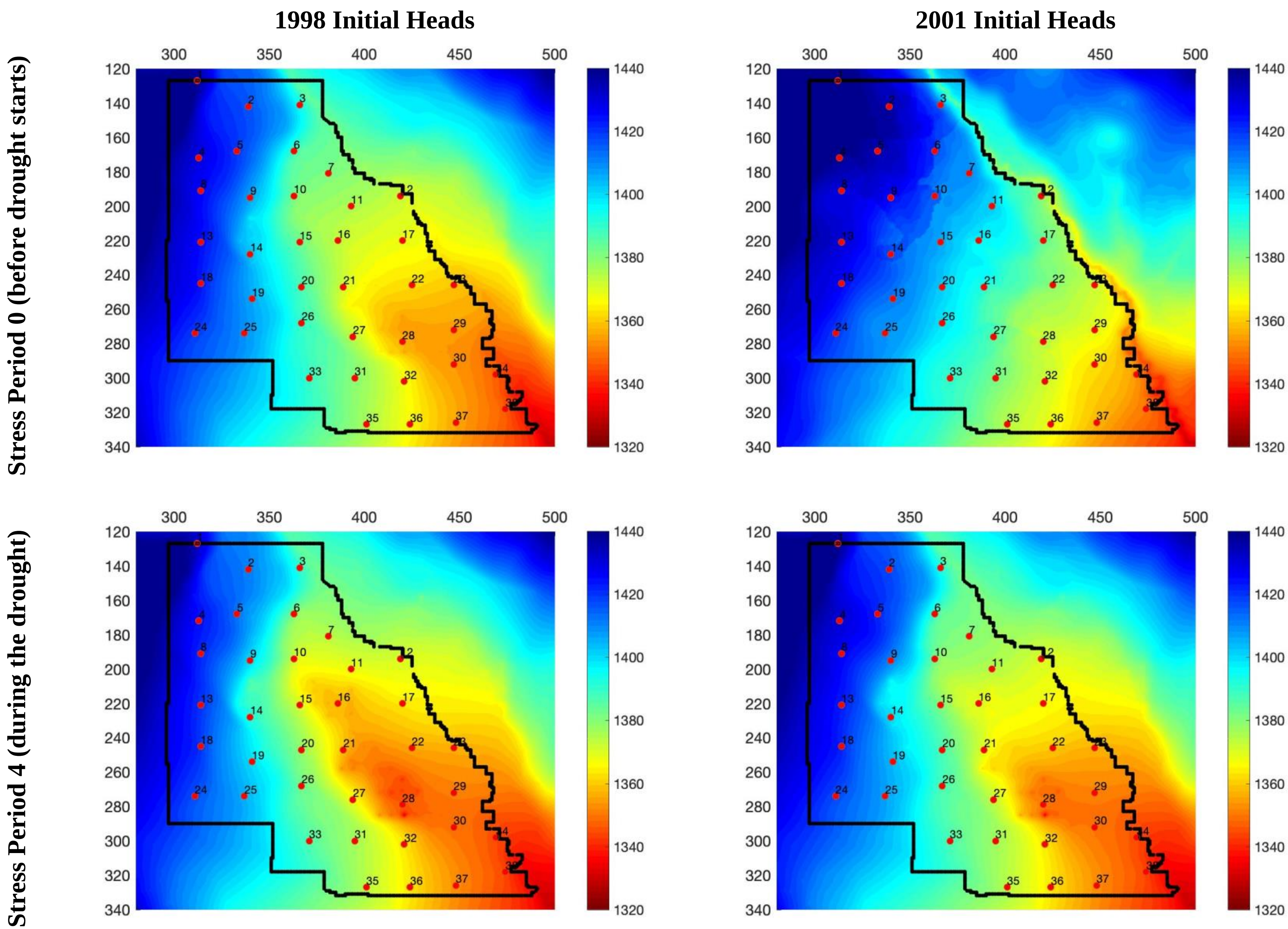

Figure 1 Annual water level changes within the BSA before, during, and after drought as well as after 2 years of recovery

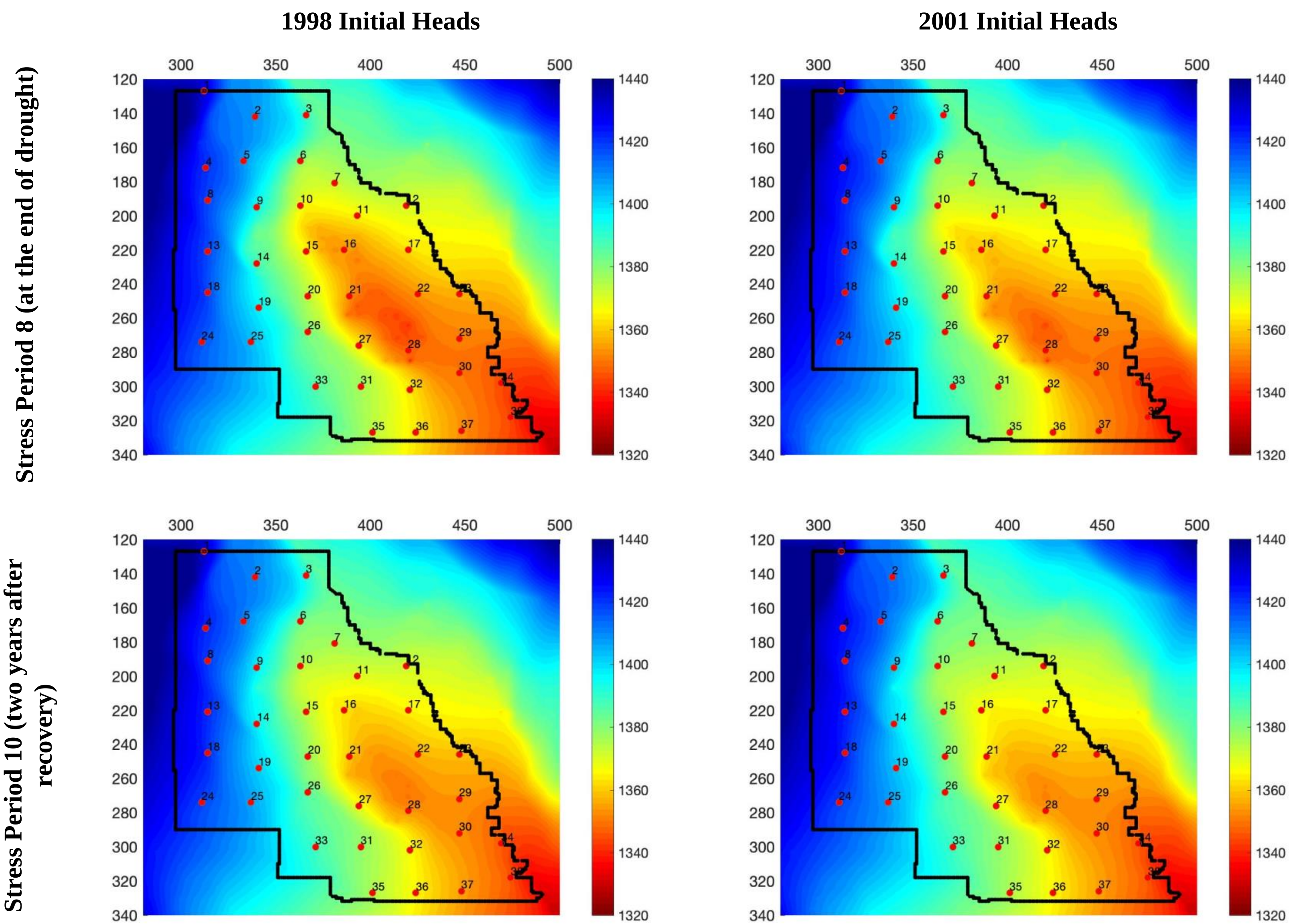

Figure 1 Continued. Annual water level changes within the BSA before, during, and after drought as well as after 2 years of recovery

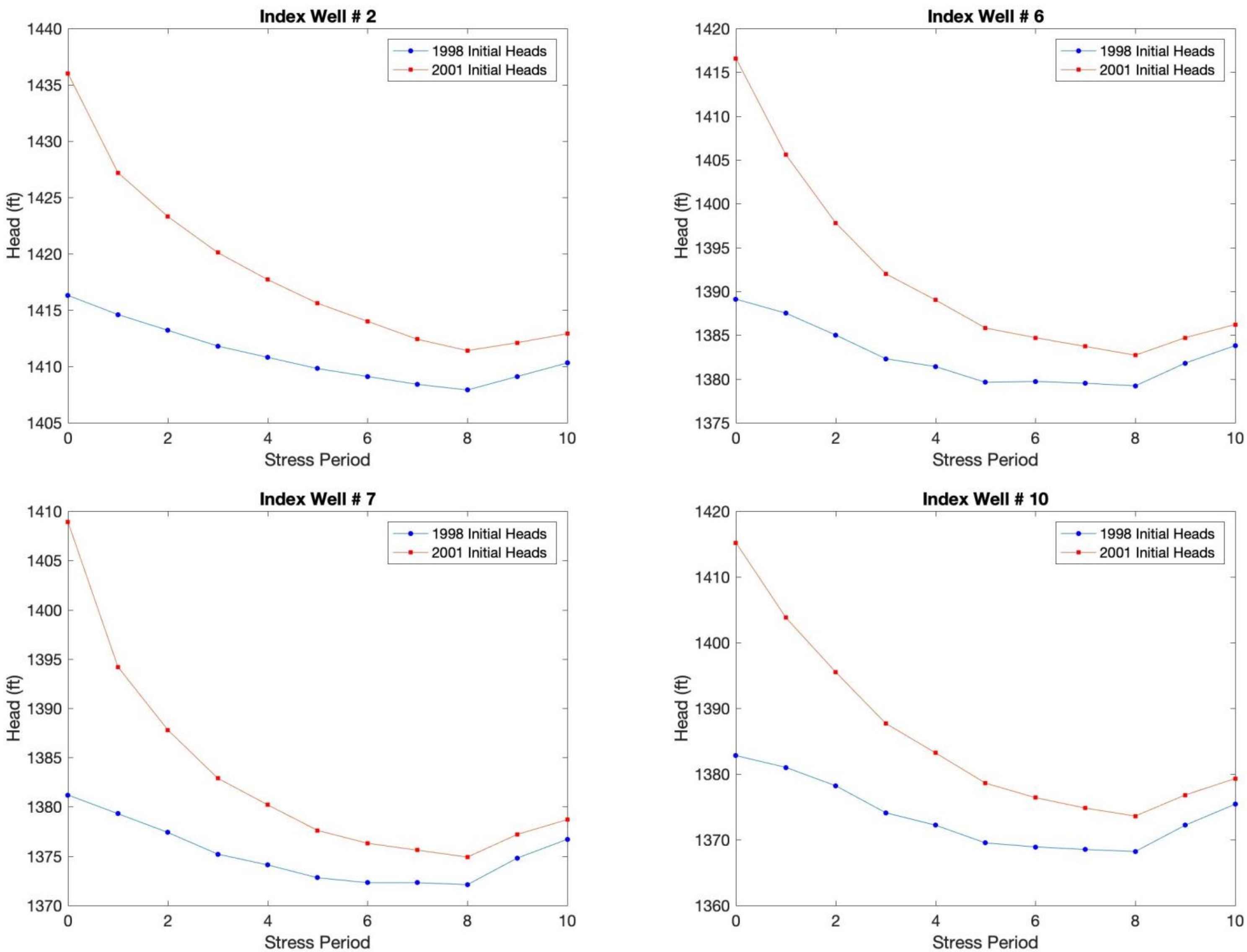

Figure 2 Annual water level changes at selected Index Wells during the 8-year drought and 2-year recovery

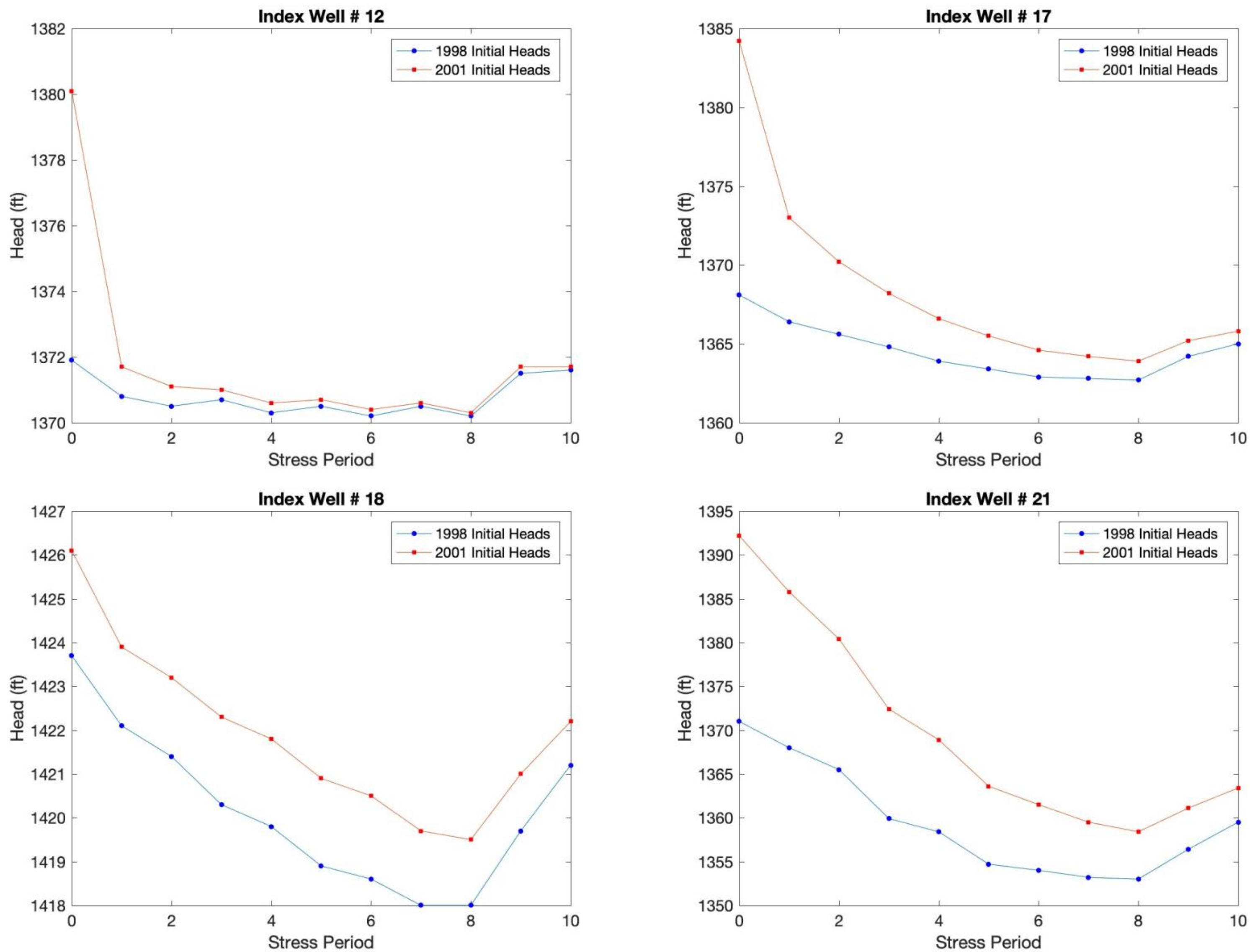

Figure 2 Continued. Annual water level changes at selected Index Wells during the 8-year drought and 2-year recovery

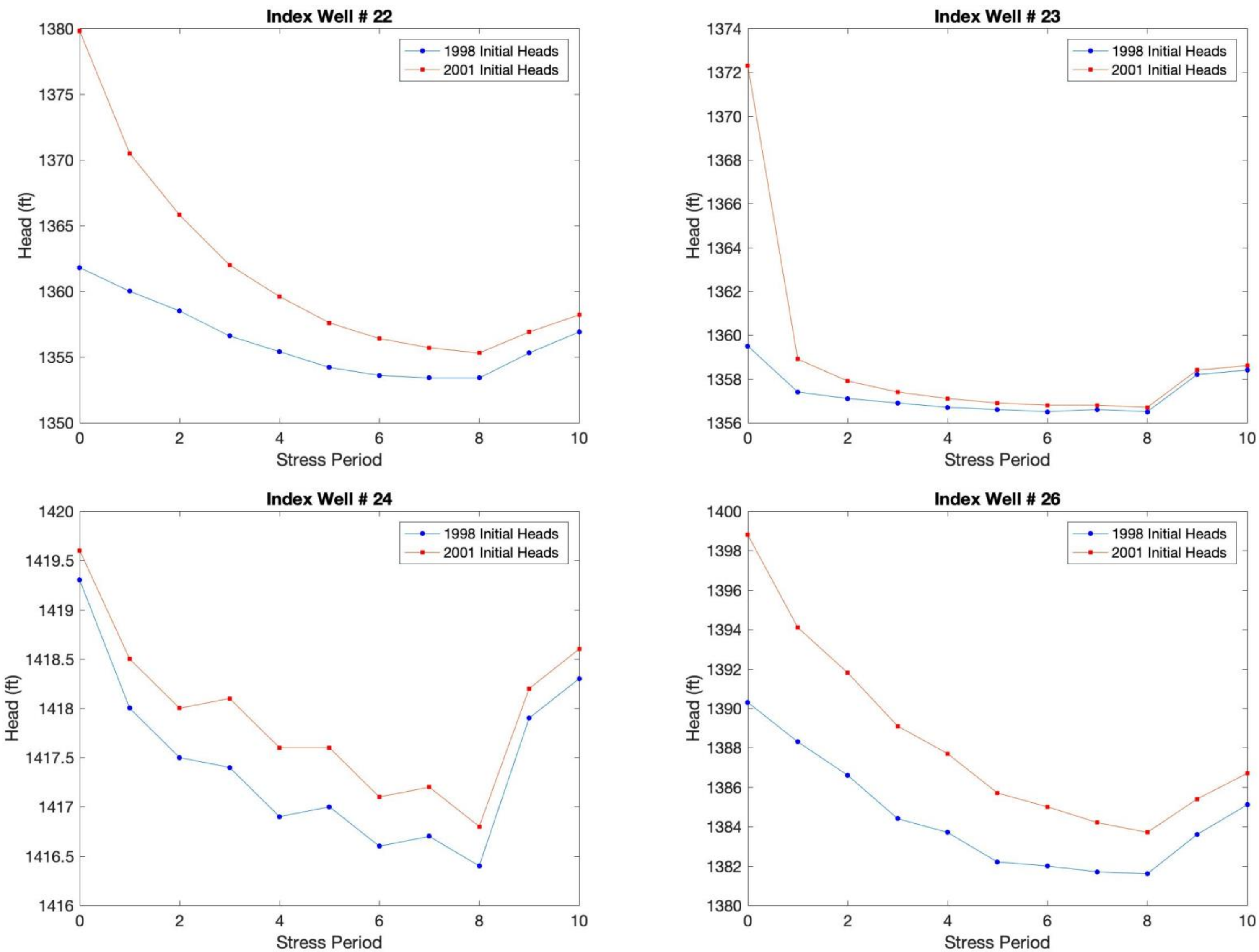

Figure 2 Continued. Annual water level changes at selected Index Wells during the 8-year drought and 2-year recovery

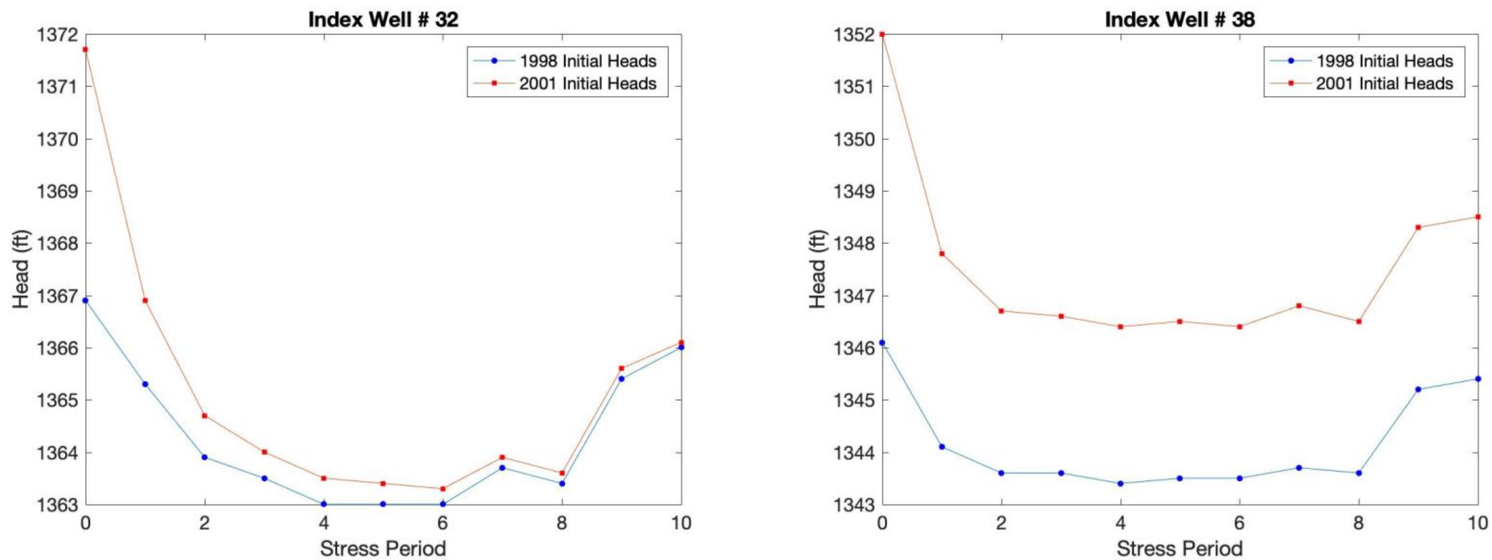

Figure 2 Continued. Annual water level changes at selected Index Wells during the 8-year drought and 2-year recovery

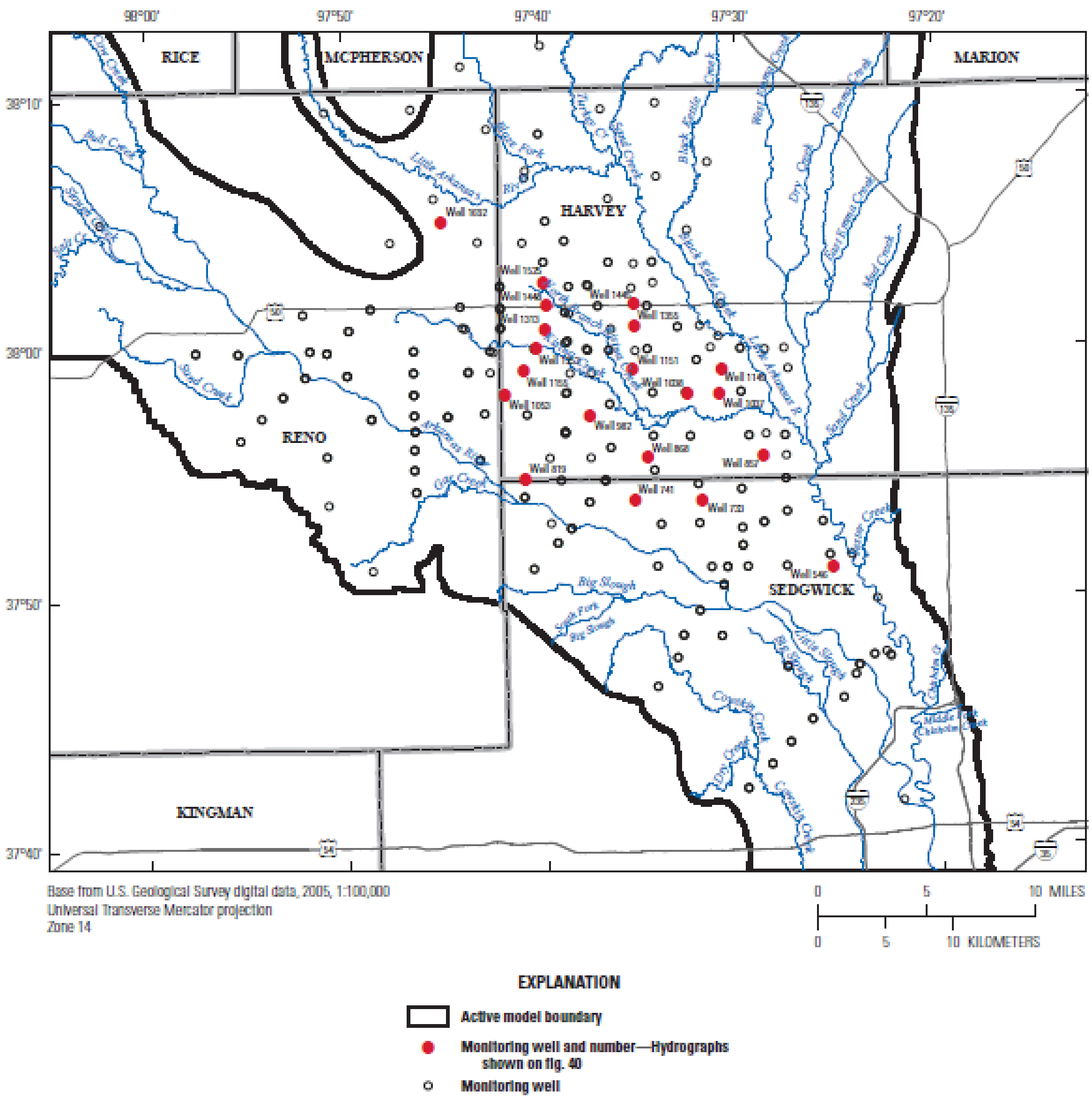

Figure 3 Copy of Figure 34 of the USGS Report: Monitoring well locations used for the transient calibration simulation

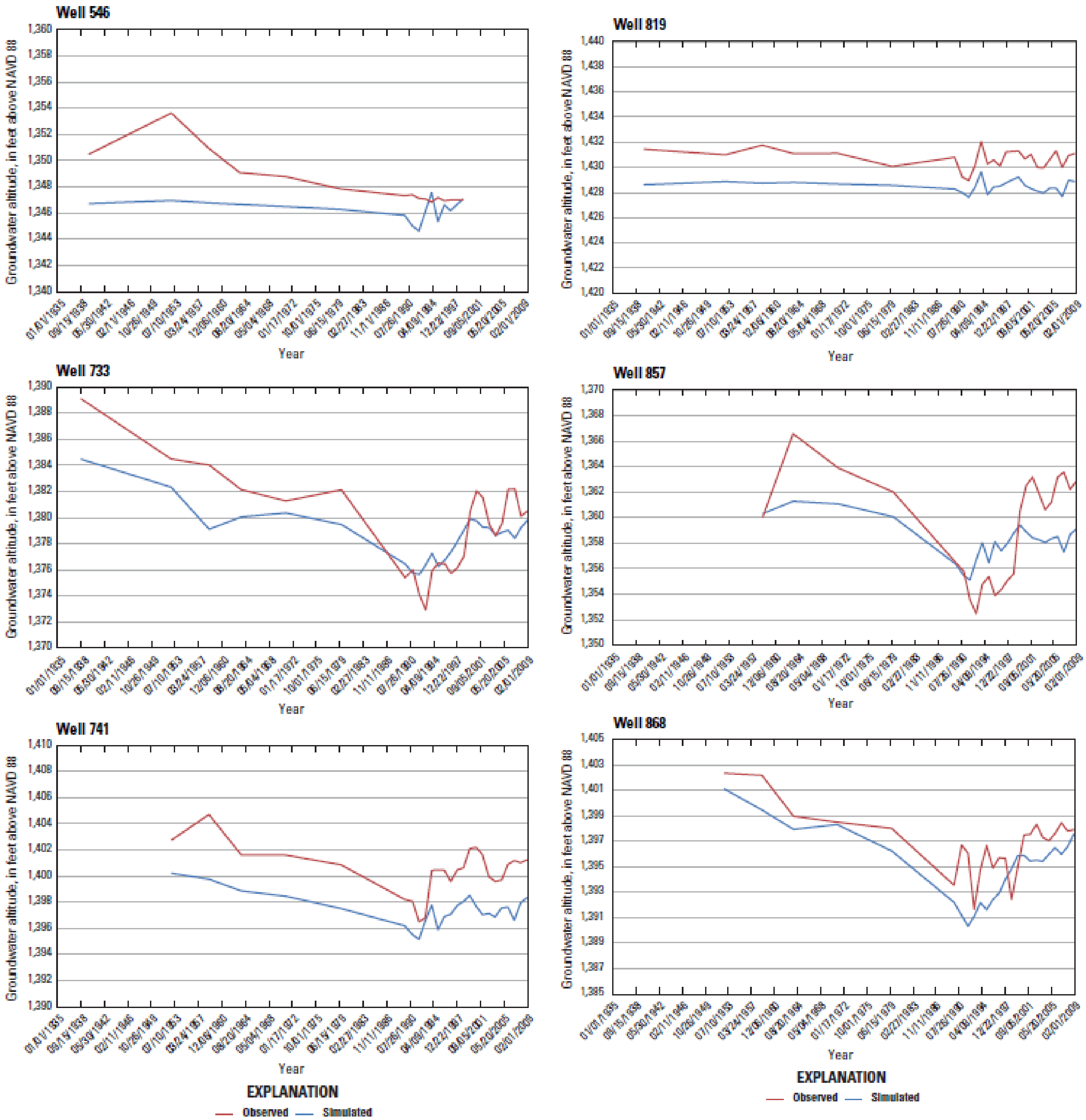

Figure 4 Copy of Figure 40 of the USGS Report: Simulated and observed groundwater levels for selected wells

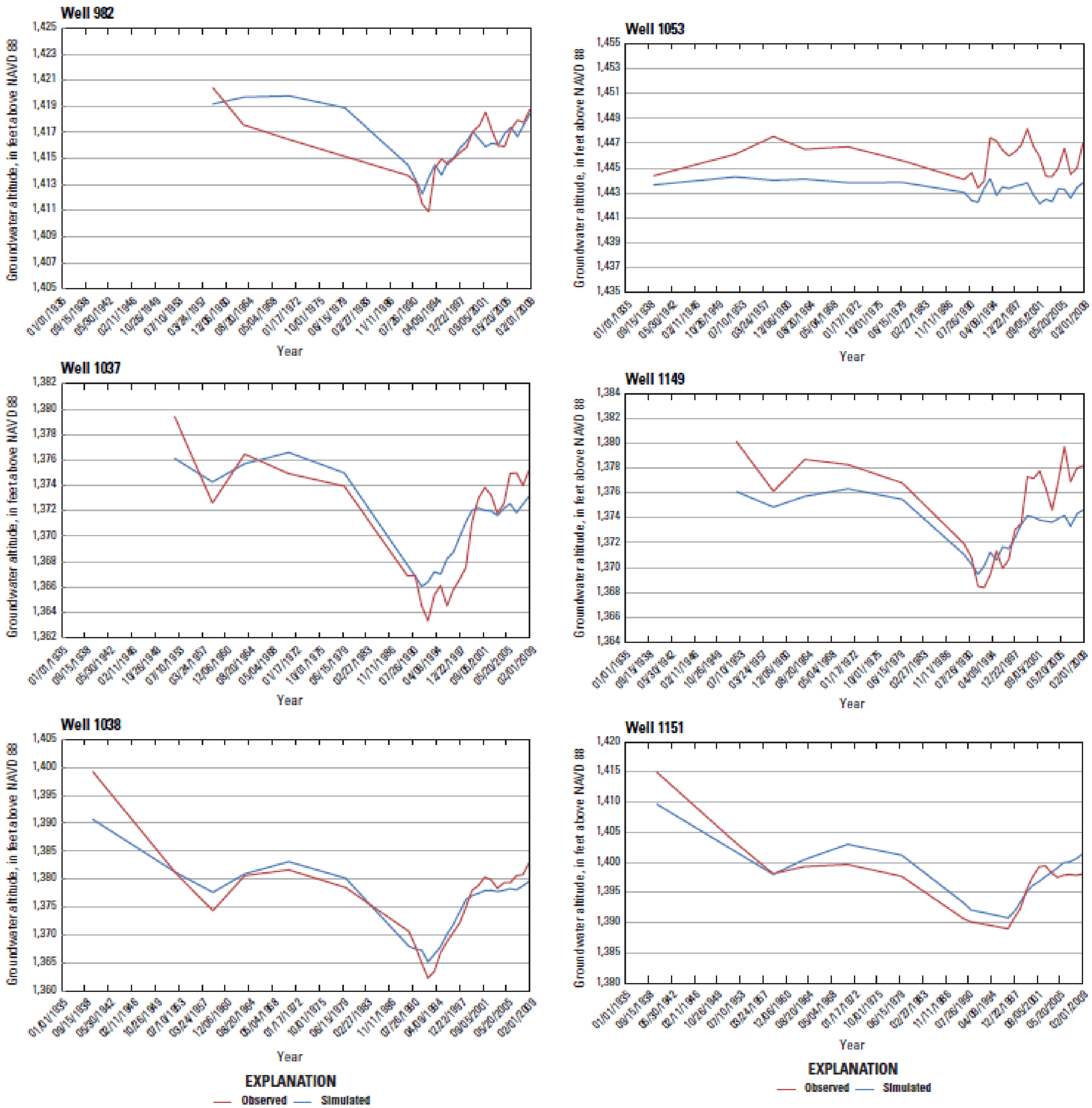

Figure 4 Continued. Copy of Figure 40 of the USGS Report: Simulated and observed groundwater levels for selected wells

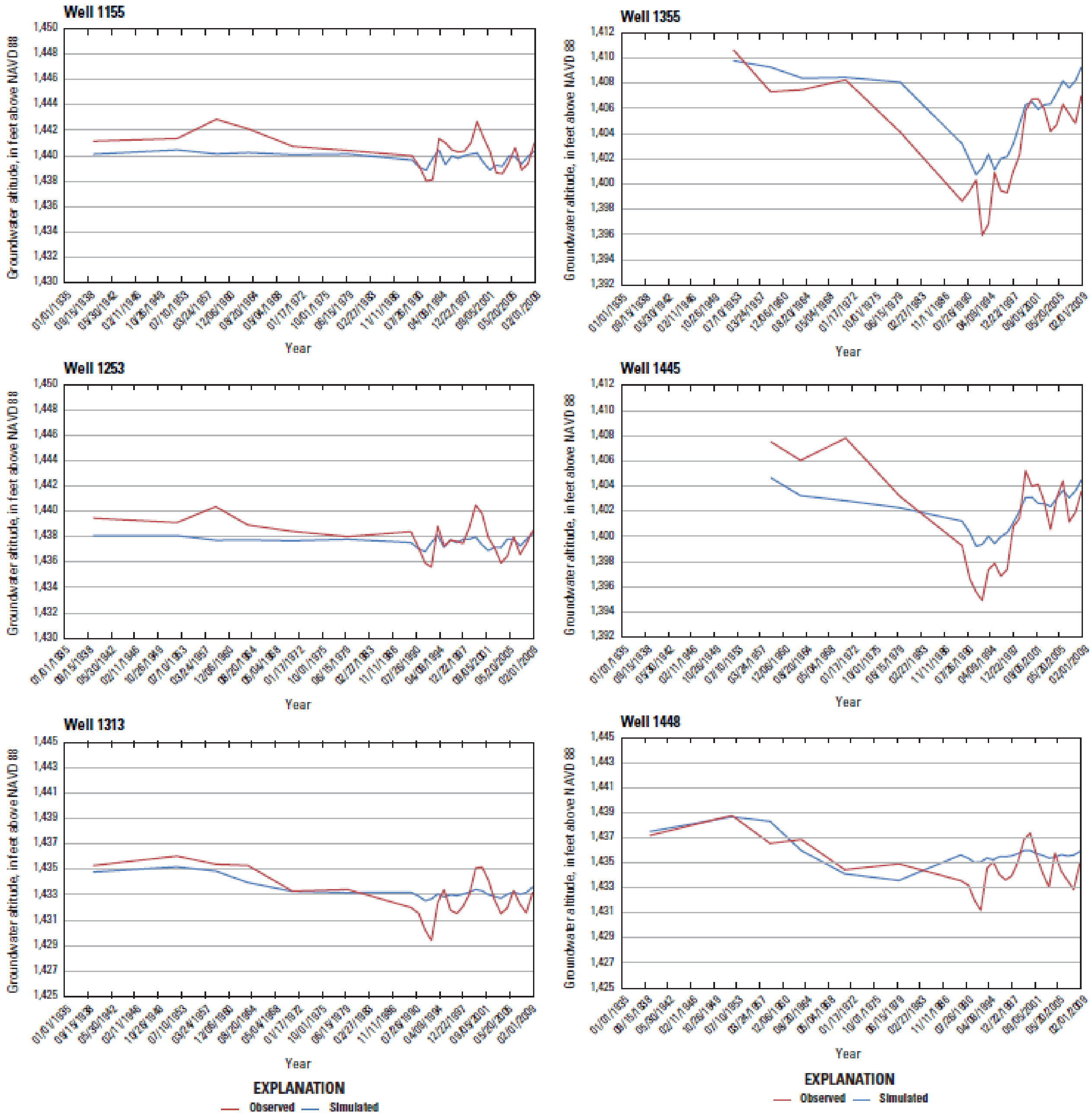

Figure 4 Continued. Copy of Figure 40 of the USGS Report: Simulated and observed groundwater levels for selected wells

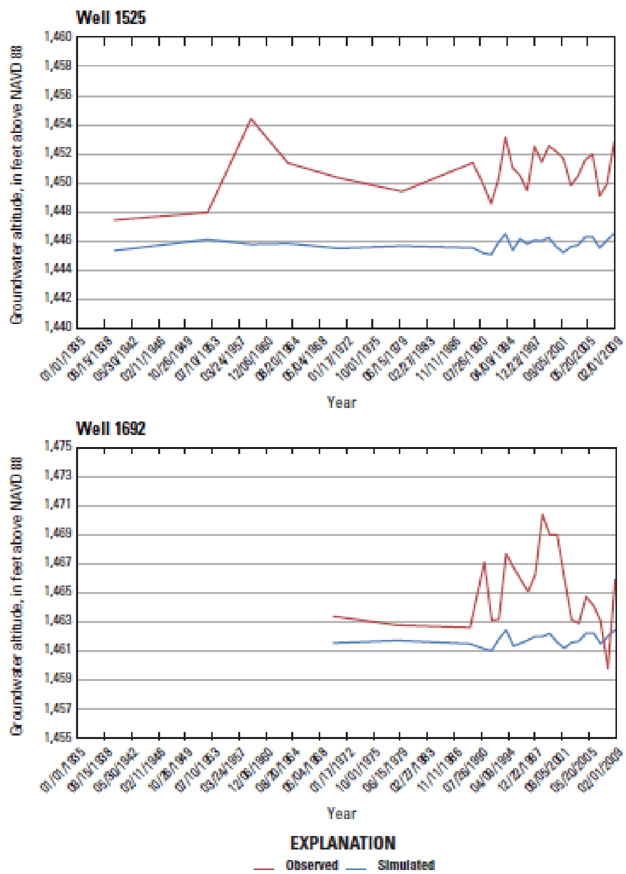

Figure 4 Continued. Copy of Figure 40 of the USGS Report: Simulated and observed groundwater levels for selected wells

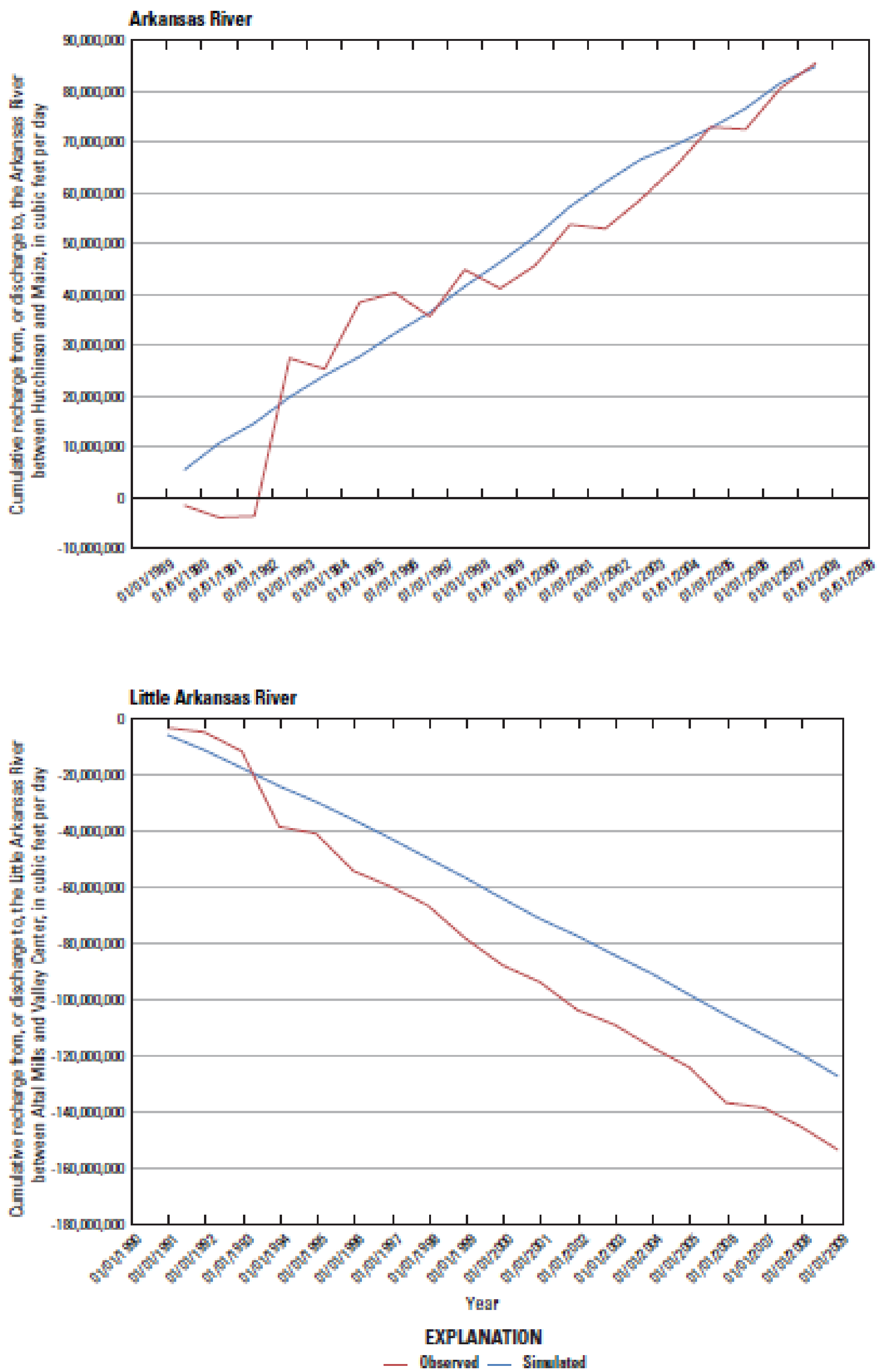

Figure 5 Copy of Figure 41 of the USGS Report: Observed and simulated cumulative streamflow gains and losses for the Arkansas and Little Arkansas Rivers for the transient simulation

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SUMMARY

Highly experienced in various facets of environmental and water resource engineering including civil and environmental engineering, computer simulation models, decision support systems, data acquisition and analysis, project management, and natural resources conservation planning.
Skilled in collaborating with all members of the organization to achieve business and financial objectives. Instrumental in streamlining and improving processes, enhancing productivity, and implementing technology solutions. Expert in interdisciplinary projects that require systemic approaches to plan and manage water supply in the context of environmental concerns, sustainability, and climate change.

EDUCATION

Ph.D. in Civil and Environmental Engineering, Aug. 2012
Department of Civil and Environmental Engineering, *Colorado State University, Fort Collins, CO*
Distinguished International Presidential Fellow
Specialization: Hydrology and Water Resources Management
Dissertation title: Models for Management of Water Conflicts – A Case Study of the San Joaquin Watershed, California
Dissertation advisor: Prof. Neil Grigg

M.S. in Civil and Environmental Engineering, Nov. 2005
Department of Civil and Environmental Engineering, *Amirkabir University of Technology (Tehran Polytechnic), Iran*
Specialization: Environmental Engineering
Thesis title: Conflict Resolution Simulation Model in River Water Quality Management
Thesis Advisor: Prof. Mohammad Karamouz

B.S. in Civil Engineering, Feb. 2002
Department of Civil Engineering, *Islamic Azad University, Nadjaf Abad, Iran*
Specialization: Water

PROFESSIONAL EXPERIENCE

2019-Present **Founder**, *Global Water Resources Solutions Inc.*, Santa Monica, CA

2018-Present **Project Engineer II**, *Larry Walker Associates*, Santa Monica, CA

1. Professional Services to Develop Groundwater Budgets and Models to Meet Sustainable Groundwater Management Act Requirements and Develop Groundwater Sustainability Plans for the Shasta, Scott and Butte Valley Groundwater Basins

2015-Present **Visiting Scholar**, *Colorado Water Institute*, *Colorado State University*, *Fort Collins:*

1. Co-advised multiple graduate students
2. Updated the design and co-facilitated an interdisciplinary short-course on Students Water Dialogue for undergraduate and graduate students
3. Co-authored a scientific report on agricultural water conservations in the Colorado River Basin

2015-2018 **Senior Water Resources Engineer**, *RTI International (formerly Riverside Technology inc.), Fort Collins, CO*

4. Basin Modeling of the Brahmaputra River System in Bangladesh, (Client: The World Bank)
5. Socioeconomic Impact Analysis for Advancing Water Supply Forecasts in the Colorado River Basin *(Client: National Aeronautics and Space Administration)*
6. Tennessee Valley Authority Hydrologic Hazard Analysis, *(Client: TVA)*
7. Idaho Power Forecast System Support, *(Client: Idaho Power)*
8. Design and Implementation of a Flood Warning Operation System for New York State Canal Corporation
9. Tennessee Valley Authority Data Analysis Support, *(Client: TVA)*

10. Applied Statistical Analysis Techniques for Hydro Generation and Runoff, *(Client: CEATI)*

2014-2015 **Postdoctoral Researcher**, *Colorado Water Institute, Colorado State University, Fort Collins*

11. Moving Forward on Agricultural Water Conservation in the Colorado River Basin, *Funded by the U.S. Department of Agriculture*
12. The U.S. Perspective on the Water-Energy-Food Nexus, *Funded by the U.S. Department of State and the Army Corps of Engineers*

May-Jul. 2014 **Consultant**, *Factor(E) Ventures, a joint venture between Shell Foundation and the Energy Institute at Colorado State University, Fort Collins, Colorado*

13. A comprehensive literature review on energy-water nexus in the developing world with specific focus on India and Sub-Saharan Africa

2012-2013 **Postdoctoral Scholar**, *Center for Watershed Sciences, John Muir Institute of the Environment, University of California, Davis*:

14. Considering Climate Change in Hydropower Relicensing, A case study of the Yuba River, *Funded by the California Energy Commission*

2008-2012 **Research Assistant**, *Department of Civil and Environmental Engineering, Colorado State University*

15. Managing conflicts over water issues in the San Joaquin Watershed, California
16. Developing methodology for cost-based decisions on water main renewal
17. Retrospective Analysis of Performance of Dual Distribution Systems
18. Modeling South Platte River Basin in ArcSWAT
19. Statistical Analysis of Irrigation Ditch Agricultural Contaminant Contribution in Weld County, Colorado
20. Denver Groundwater Availability for Supplying Domestic Water Demands

2007 – 2008 **Project Engineer**, *Yekom Consulting Engineers Company, Tehran, Iran*

21. The Sefidrood River Water Pollution Prevention, Control and Reduction
22. Environmental Impacts Assessment of the Takestan Irrigation and Drainage System

2004 – 2008 **Research Assistant**, *Water and Environment Research and Development, affiliated with the University of Tehran, Iran*

23. Qualitative and Quantitative Planning and Management of Water Allocation with Emphasis on Conflict Resolution, *Funded by the Department of Environment (DOE), Iran*
24. Design of the Karoon Water Quality Monitoring System and Bid Evaluation Assistance, *Funded by the World Bank*
25. Assessment of Water Quality Management in the Province of Khuzestan in Iran, *Funded by the World Bank*
26. Statistical Analysis of Water Quality Variation in Karoon River and Selection of Water Quality Indicators for the Monitoring System, *Funded by the DOE, Iran*
27. Master Plan for Air Pollution Control in Abadan City, *Funded by the DOE, Iran*

PUBLICATIONS

Books

1. Karamouz, M., A. Ahmadi, and **M. Akhbari**, 2011. "Groundwater Hydrology: Engineering, Planning, and Management," *CRC Publishing*, Boca Raton, FL.
2. Karamouz, M., A. Ahmadi, and **M. Akhbari**, 2011. "Solution Manual - Groundwater Hydrology: Engineering, Planning, and Management," *CRC Publishing*, Boca Raton, FL.

Peer Reviewed Publications

1. Khaksar, M.A., Monghasemi, S., **Akhabri, M.,** and M. Nikoo (In Review), "Bargaining and Voting in an Agent-based Modeling Framework for Water Resources Conflict Management", *Journal of Hydroinformatics*.

2. Islami, I., Sadoddin, A., Asgharpour Masoule, A., and **M. Akhbari** 2017, "Modeling socio-ecological structure of stakeholders' participation in managing livestock drinking water using the agent-based approach," *Applied Ecology and Environmental Research*, DOI: http://dx.doi.org/10.15666/aeer/1503_11731192.
3. Islami, I., Sadoddin, A., Barani, H., Asgharpour Masoule, A., and **M. Akhbari** 2016 "Analysis of the barriers to public participation in livestock water management in Yazd's rangelands using Delphi technique," Journal of Rangeland—in Farsi.
4. Farhadi, S., Nikoo, M., Rakhshanderoo, G., **Akhbari, M.**, and M.R. Alizadeh 2016, "An Agent-based-Nash Modeling Framework for Sustainable Groundwater Management: A Case Study," *Journal of Agricultural Water Management*, DOI: 10.1016/j.agwat.2016.08.018
5. **Akhbari, M.** and N. S. Grigg 2015, "Managing Water Resources Conflicts: Modelling Behavior in a Decision Tool," *Journal of Water Resources Management*, Springer, Volume 29, Issue 14, Page 5201-5216 DOI: 10.1007/s11269-015-1113-9.
6. **Akhbari, M.** and N. S. Grigg 2014. "Water Management Tradeoffs between Agriculture and the Environment: A Multiobjective Approach and Application," *J. of Irrig. and Drainage Eng.*, ASCE, Vol. 140, Issue 8, DOI: 10.1061/(ASCE)IR.1943-4774.0000737.
7. **Akhbari, M.** and N. S. Grigg 2013. "A Framework for an Agent-Based Model to Manage Water Resources Conflicts," *Journal of Water Resources Management*, Springer, Vol. 27, Issue 11, pp. 4039-4052, DOI: 10.1007/s11269-013-0394-0.
8. Karamouz, M., **M. Akhbari**, and A. Moridi, 2011. "Resolving Disputes over Reservoir-River Operation," *J. of Irrigation and Drainage Engineering*, ASCE, Vol. 137, No. 5, pp. 327-339, DOI: 10.1061/(ASCE)IR.1943-4774.0000292.
9. Karamouz, M., Kerachian, R., **M. Akhbari,** and B. Haafez 2009. "Design of river water quality monitoring networks: a case study," *J. of Env. Modeling and Assessment*, Springers, 14(6), pp. 705-714, DOI: 10.1007/s10666-008-9172-4
10. Karamouz, M., Kerachian, R., Nikpanah, A. and **M. Akhbari** 2008. "Management Information System for River Quality Data Analysis, Case Study: Karoon and Dez Rivers," *Journal of Iran Water Resources Research*, Vol. 4, No. 1, 9-27 (in Farsi).
11. Karamouz, M., **M. Akhbari**, R. Kerachian, and A. Moridi 2006. "A System Dynamics-Based Conflict Resolution Model for River Water Quality Management," *Iranian Journal of Environmental Health Science and Engineering,* Vol 3, No. 3, pages 147-160.

Reports

1. **Akhbari, M.,** Smith, MLou 2016. "Case Studies Highlighting Challenges and Opportunities for Agricultural Water Conservation in the Colorado River Basin," Colorado Water Institute, Special Report No. 27. Available at: http://cwi.colostate.edu/publications/SR/27.pdf
2. **Akhbari, M.,** Grigg, N. S., and R. Waskom 2014. "Background Paper for the Nexus Workshop: U.S. Perspective on the Water-Energy-Food Nexus," The Nexus Dialogue on Water Infrastructure Solutions Meeting, Golden, Colorado, June 23-24, 2014. Available at: http://www.cwi.colostate.edu/workshops/NEXUS2014/Background.aspx
3. Akhbari, M., Childress, A. Averyt, K., Barton, J., Bellamy, B., Belt, R., Chartrand, L., Cohen, M., Gilroy, K., Grigg, N., Harto, C., Holzfaster, J., Kryc, K., Laituri, M., Lineberger, J., MacDonnell, L., Macknick, J., Marshall, Z., Radtke, J., Spang, E., Tellenhuisen, S., Tidwell, V., Waskom, R. 2014. "Report from the U.S. Nexus Workshop — Water, Energy, and Food: Mutual Security through a Nexus Approach," in U.S. Perspective on the Water-Energy-Food Nexus, Colorado Water Institute, Information Series No. 116. Available at: http://www.cwi.colostate.edu/workshops/NEXUS2014/Report.aspx
4. Waskom R., **Akhbari, M.,** and Grigg, N. S. 2014. "U.S. Perspective on the Water-Energy-Food Nexus," Colorado Water Institute, Information Series No. 116. Available at: http://www.cwi.colostate.edu/workshops/NEXUS2014/Proceedings.aspx
5. Viers, JH, Rheinheimer, D., **Akhbari, M.**, Peek, R., Yarnell, S., Null, S. 2013. "Considering climate change for hydropower relicensing." Public Interest Energy Research (PIER) Program White Paper. Prepared for the California Energy Commission.

Talks and Presentations (* denotes the presenter)

1. **Akhbari*, M.** 2015, "Co-management of Water, Energy, and Food Systems: Where Are We and What Does it Take for Implementation?" *2015 American Geophysical Union Fall Meeting*, San Francisco, California. (poster)
2. **Akhbari*, M.** and R. Waskom 2015, "Enhancing Water-Energy-Food Security: Primary Challenges and Opportunities," *American Water Resources Association (AWRA) Annual Conference on Water Resources.*
3. **Akhbari*, M.,** Smith, MLou and R. Waskom 2015, "Saving Agricultural Water in the Colorado River Basin: Drivers and Challenges," *American Water Res. Association (AWRA) Annual Conference on Water Resources*.
4. **Akhbari*, M.** 2015 (Invited), Systemic Approaches in Planning and Management of Water, Energy, and Food Resources: Employing Agent-Based Modeling as a Supporting Tool, *Shiraz University*, Shiraz, Iran.
5. **Akhbari*, M.,** Grigg, N. S., and R. Waskom 2014. "Water-Energy-Food Nexus: Compelling Issues for Geophysical Research," *2014 American Geophysical Union Fall Meeting*, San Francisco, California.
6. Macknick*, J., Waskom, R., Grigg, N.S., **Akhbari, M.** 2014. "Case Studies and Perspectives on the Water-Energy-Food Nexus in the United States," *Symposium on Infrastructure Solutions in the Water-Energy-Food Nexus*, Beijing, China.
7. Waskom*, R., Taylor, P.L., Eckhardt, L., Cabot, P., Smith, MLou, Macilroy, K., Love, H., **Akhbari, M.,** and Kallenberger, J. 2014. "Moving Forward on Agricultural Water Conservation in the Colorado River Basin," *National Integrated Water Quality and Agriculture and Food Research Initiative Project Director's Meeting*, Washington D.C (poster).
8. Waskom*, R., Grigg, N.S., **Akhbari, M.** 2014. "Report from the U.S. — Water Energy Food Nexus Workshop," *2014 World Water Week*, Stockholm, Sweden.
9. **Akhbari*, M.** (2014), "California Bay-Delta Program," *The Nexus Dialogue on Water Infrastructure Solutions Meeting*, Golden, Colorado, June 23-24, 2014.
10. Null*, S.E., **Akhbari, M.**, Ligare, S.T., D. Rheinheimer, D., Peek, R., Yarnell, S.M., and J.H. Viers 2013. "Modeling Climate Change Effects on Stream Temperatures in Regulated Rivers," *2013 American Geophysical Union Fall Meeting*, San Francisco, California (poster).
11. Rheinheimer*, D.E., **Akhbari, M.**, Peek, R., Yarnell, S.M., Null, S.E., Viers, J.H. 2013. "Incorporating climate change in flow regime alteration studies in hydropower licensing." *2013 American Geophysical Union Fall Meeting*. San Francisco, CA.
12. **Akhbari*, M.**, Null, S.E., Viers J.H., and D. Rheinheimer 2012. "A Framework for Incorporating Hydroclimate Variability in Regulated Rivers: Implications for Hydropower Relicensing in California's Yuba River," *2012 American Geophysical Union Fall Meeting*, San Francisco, California.
13. **Akhbari*, M.** and N. S. Grigg 2011. "Conflicts over Water Quality Management in Sacramento-San Joaquin Delta," *AGU Hydrology Days*, Colorado State University, Fort Collins, Colorado.
14. Cowley*, C.T., **Akhbari, M.** NegahbanAzar, M. Arabi, M. and K. Carlson 2010. "Geospatial Analysis of the Occurrence and Transport of Antibiotics in Irrigation Ditches and the Poudre River in Weld County," AGU Hydrology Days, Colorado State University, Fort Collins, Colorado.
15. Karamouz, M., **M. Akhbari***, R. Kerachian, and A. Moridi 2006. "Conflict Resolution in River Water Quality Management: A System Dynamics Approach," *7th International Conference in Civil Engineering*, Tarbiat Modarres University, Tehran, Iran.

TEACHING EXPERIENCE

Fall 2015	**Guest Lecturer**, *Colorado River Water: Wicked Problems*, Colorado Water Diplomats, Colorado State University, Fort Collins, CO
Fall 2012	**Guest Lecturer**, *Physical Geography*, Department of Watershed Sciences, Utah State University, Logan, Utah
Summer 2011	**Teaching Assistant**, *Dynamics*, Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado
2007 - 2008	**Lecturer**, *Preparation for Master's Degree Examination competition*, University Jahad Training Center – Affiliated with the University of Tehran
Fall 2004	**Teaching Assistant**, *Systems Engineering for Civil Engineers*, Department of Civil Engineering, University of Tehran

Spring 2005 **Teaching Assistant**, *Systems Engineering for Civil Engineers*, Department of Civil and Environmental Engineering, Amirkabir University of Technology (Tehran Polytechnic)

EDUCATIONAL INNOVATION AND EXPERIENCE

2014-2017 **Co-advisor**:

1. Milad Ghalleban, Ph.D. in Water Resources Engineering, Bu-Ali Sina University, Hamedan, Iran (since May 2014).
   Dissertation topic: *Identification of Practical Solutions to Control Exploitation of Water Resources in Qazvin Plain: Application of Agent-based Modeling.*
2. Saeid Najjar, M.S. in Civil Engineering, Tabriz University, Tabriz, Iran (graduated in Fall 2017).
   Thesis topic: *Agent-based Modeling for Sustainable Groundwater Management in Ardabil Plain.*
3. Iman Islami, Ph.D. in Desertification Control, Gorgan University of Agricultural Sciences and Natural Resources, Iran (graduated in Spring 2017).
   Dissertation topic: *Assessing Rangelands Stakeholders' Participation in Management of Livestock Drinking Water Using an Agent-Based Approach—Case Study: Arid Rangelands of Yazd Province.*
4. Saber Farhadi, M.S. in Civil and Environmental Engineering, Shiraz University, Shiraz, Iran (graduated in Spring 2016).
   Thesis topic: *Developing a multi-agent model to optimize the qualitative-quantitative management of groundwater for agricultural, industrial and municipal purposes.*

Fall 2015 **Facilitator**, *Students in Water Dialogue*, Colorado State University
Co-designed and co-facilitated a four-week interdisciplinary course for undergraduate and graduate students from different disciplines, departments, and backgrounds to help them expand their perspective about water-related wicked problems, especially in the West, and develop skills on how to productively engage in/ or facilitate water conflicts.

PROFESSIONAL ACTIVITIES

Review Panelist: 2017 National Science Foundation, Graduate Research Fellowship Program

Session Chair and Convener:
"*Global and regional water-food-energy security under changing environments*," American Geophysical Union, 2015 Fall Meeting, San Francisco, CA

Reviewer for the following journals:

- J. of Water Resources Management (ASCE)
- J. of Irrigation and Drainage Eng. (ASCE)
- Journal of Hydrologic Engineering (ASCE)
- Journal of American Water Resources Association
- Ecology and Society
- PLOS ONE
- British J. of Environment and Climate Change

Judge: *Outstanding Student Paper Awards*, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA

Organizer: Webinar, "*Moving Forward on Agricultural Water Conservation in the Colorado River Basin*," Colorado State University, September 3, 2014.

Facilitator: "*U.S. Lessons Learned*," The Nexus Dialogue on Water Infrastructure Solutions Meeting, Golden, Colorado, June 23-24, 2014.

SKILLS/SPECIALTIES

Computer:

- MODFLOW, ModelMuse, RiverWare, ArcGIS, ArcSWAT, WEAP21, RTEMP, WQRRS, JMP, Indicators of Hydrologic Alteration (IHA), Time Series Tool (TSTool), Microsoft Office (Word, Excel, Access, PowerPoint, Visio), PowerPivot, Programming in Python, MATLAB, and R

- Familiar with UNIX, DSM2, HEC-DSS, MIKE CUSTOMIZED, Interactive Calibration Program (ICP), National Weather Service River Forecast System (NWSRFS), Interactive Double Mass Analysis Program (IDMA), and Programming in FORTRAN

Languages:

- Persian/Farsi (native fluency), English (fluent), Arabic (basic)

LEADERSHIP AND INVOLVEMENT

2009-2012 **Cultural Mentor**, *Office of International Programs, Colorado State University (CSU), Fort Collins, CO*

- Assisting more than 800 new international students
- Assisting with orientation sessions
- Facilitating small group discussions during orientations
- Maintaining communication throughout the semester to make sure the students have a successful transition into the American culture
- Serving as a knowledgeable, friendly, and culturally sensitive representative of CSU

2010-2012 **Community Coordinator**, *Apartment Life, Housing and Dining Services, Colorado State University, Fort Collins, CO*

<u>Awarded “Spirit of Apartment Life” for outstanding leadership, community building and communication</u>

- Providing service to more than 500 American and international students
- Implementing and evaluating a variety of educational, social, and cultural programs to promote community development
- Managing conflicts between the community members
- Serving as an active member of Apartment Life programming and training committees
- Acting as staff for large-scale events in area and on campus
- Making initial contact with new members of the community and on an ongoing basis thereafter
- Writing articles for the Apartment Life newsletter

2011 -2012 **Improving Teaching Skills Seminars**, outlined based on ASCE Teaching Workshops on the “ExCEEd Model,” *Attended at Colorado State University, Fort Collins, CO*

- Principles of effective teaching
- Students’ learning styles
- Organizing a class
- Writing skills
- Speaking skills

May 2011 **The LeaderShape Institute**, *Pingree Park, Colorado State University-Mountain Campus, CO*

- Attended and Graduated from the LeaderShape program, a week-long program to learn how to respect diversity and lead with integrity
- Learned an effective method of leadership and accomplishing large visions
- Learned how to:
    - Act consistently with core and ethical values, personal values and convictions
    - Enlarge leadership capacity
    - Develop and enrich relationships
    - Respect the dignity and contributions of all people
    - Believe in a healthy disregard for the impossible

STATE OF KANSAS
BEFORE THE DIVISION OF WATER RESOURCES
KANSAS DEPARTMENT OF AGRICULTURE

In the Matter of the City of Wichita's	**)**	
Phase II Aquifer Storage and Recovery Project	**)**	**Case No. 18 WATER 14014**
in Harvey and Sedgwick Counties, Kansas	**)**	
	)	

Pursuant to K.S.A. 82a-1901 and K.A.R. 5-14-3a.

TECHNICAL ASSESSMENT

ASR PERMIT MODIFICATION PROPOSAL
REVISED MINIMUM INDEX LEVELS & AQUIFER MAINTENANCE CREDITS

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INTRODUCTION

Balleau Groundwater, Inc. (BGW) has been retained by Wendling Law, LLC and Adrian & Pankratz, P.A. to provide technical information and opinions regarding hydrologic effects associated with City of Wichita ASR Permit Modification Proposal (hereafter "the Proposal") (Burns & McDonnell, 2018a). Wendling Law, LLC provided model files and a transmittal (Macey, 2018) with the files associated with the City of Wichita Aquifer Storage and Recovery (ASR) Permit Modification Proposal. The City's ASR Permit Modification Proposal includes analysis based on the USGS model (Kelly and others, 2013) of the Equus Beds aquifer. Burns & McDonnell (BMcD) performed the model analysis. The USGS model provides a technical basis for the City's Proposal and for annual accounting (Burns & McDonnell, 2018b) of ASR recharge credits compatible with a condition of approval in existing permits required to capture, store and recover water for the City's beneficial use. BGW's assessment of hydrologic effects related to the City's Proposal emphasizes information contained in the Proposal and considers related technical documents (listed in the references section of this report). BGW also obtained a copy of the original distribution of the USGS model to inspect the files and modeled water budget.

As part of the technical assessment, we inspected and ran the model files the City (Macey, 2018) provided and compared the files to the original USGS files. In the course of doing so, we observed a difference between specifications in the USGS model and the model provided by the City, namely the ratio of horizontal to vertical hydraulic conductivity simulated between model layers. BMcD reports that no changes were made to the original construction or hydrogeologic properties of the original USGS model (Burns & McDonnell, 2018a, p. 2-7 and 2018b, p. 4-1). The reason for the change is not clear. The upshot is that we found the alteration to model specifications does not result in a significant change to certain technical aspects we evaluated in the Proposal. For example, we evaluated the BMcD analysis that defines the proposed minimum index levels in both model versions and found the change is on the order of a few feet or less. However, unless there is a reason to deviate from the original USGS model concept, we recommend the City accounting of recharge credit and the analysis in the Proposal be updated accordingly to confirm that other potentially significant factors do not turn up. Keeping the ratio of horizontal to vertical hydraulic conductivity the same as in the USGS model should improve simulation of hydrologic conditions in west Harvey County (northwest corner of the basin storage area) where anisotropy between model layers is known to occur. The description of the ratio of horizontal to vertical hydraulic conductivity represented in the model is described by the USGS (Kelly and others, 2013, p. 34).

In our technical assessment, we evaluated the City's Proposal using the model as provided by the City and using the USGS model in its original form. We found that the results in both sets of model simulations are not different enough to affect our overall conclusions. To remain consistent with the original USGS concept, herein we present results from our assessment with the model in its original USGS form.

HYDROLOGIC EFFECTS OF 1% DROUGHT SIMULATION IN PROPOSAL

BMcD describes the 1% drought simulation in the Proposal to stem from a decision by the City to utilize a 1% exceedance probability drought for resource planning of future water supplies. The decision prompted BMcD to develop a drought analysis with the USGS model to assess hydrologic conditions in the Basin Storage Area (BSA). In the process of evaluating scenarios of prolonged drought, BMcD found that some water levels in the BSA[1] are projected to drop below the minimum index water levels, which triggers a condition that prevents diversion of ASR recharge credit water in the City's current ASR permit. Accordingly, BMcD's analysis is the technical basis for the Proposal to revise the minimum index levels by lowering them so the City could divert ASR recharge credit water during an extended drought.

The BMcD analysis in the Proposal presents results of the 1% drought simulation in the context of water-level elevations and percent of saturated thickness of the aquifer. The results are based on the total City pumping (non-credit and ASR recharge credit) represented in the 1% drought simulation (Burns & McDonnell, 2018a, Table 2-5). The model has the capability of isolating hydrologic effects from components of City pumping. For example, the BMcD 1% drought analysis can be adapted to quantify the hydrologic effect of pumping the ASR recharge credit. **Figure 1** shows how the hydrologic system responds to City ASR recharge credit pumping in the 1% drought simulation. Initially, the pumping produces most of the water from aquifer storage, but as pumping continues, the cone of depression from groundwater pumping induces (depletes) flow from the Little Arkansas and Arkansas rivers. A notable observation on **Figure 1** is that stream depletion continues to occur for years after groundwater pumping ceases. This lagged depletion response occurs because, even though pumping has stopped, stream depletion continues to fill in the cone of depression that was caused when the well was pumping.

The proximity of the City wells to the rivers results in groundwater operations (diversion/injection) affecting river flow within one year of pumping. Below we expand on this technical approach of analyzing hydrologic effects from different components of City pumping (**Figure 1**) with an examination of hydrologic effects that considers an example of diverting groundwater that causes drawdown to the level of the proposed minimum index level.

[1] In the Proposal, BMcD reports that water levels in about half of the index cells lowered below the current minimum index level in their 1% drought analysis (Burns & McDonnell, 2018a, Table 2-10).

The BMcD 1% drought analysis results in some water levels in the BSA dropping below the current minimum index level, thereby preventing the City from diverting ASR credit water. To clarify, the revised minimum index levels in the Proposal do not directly represent the modeled water levels in the BMcD drought analysis. To determine the revised minimum index level in the Proposal, BMcD added a contingency to the water levels modeled at the end of the drought simulation. That is, the proposed minimum index levels are at a lower elevation than that modeled in the 1% drought analysis. We are interested in quantifying hydrologic effects associated with the City potentially diverting ASR recharge credit from the depth limited by the proposed minimum index level. Accordingly, to quantify the hydrologic effects associated with the Proposal, model analysis in addition to the BMcD scenario is needed.

In our assessment of City groundwater pumping, we used the model to quantify hydrologic effects from three categories of pumping: **A**) diversion of groundwater without ASR credit (i.e. pumping 40,000 AF/y), **B**) diversion of ASR recharge credit water with the constraint of the existing minimum index level (1993 level) and **C**) diversion of ASR recharge credit water with the lowering of the existing minimum index level to the proposed level. The analysis approach allows for quantifying the potential hydrologic effect of the Proposal (i.e. presenting an example of hydrologic effects if the City diverted groundwater that caused drawdown to the proposed minimum index level). An assessment of the categories of pumping associated with causing drawdown to the minimum index levels is possible with the Multi-Node Well package (Konikow and other, 2009) that is used in the USGS model.

The MNW package has utility for analyzing well yield that is limited in association with a lowered pumping water level, typically near the pump intake. For example, when the pumping water level in a well approaches the pump intake, a threshold is eventually crossed when the yield must decline to prevent air from entering the intake. That threshold can be set as a limit in the modeled representation of pumping wells. The same concept can be used to estimate credit water diverted from City wells by setting a limit that matches the minimum index water level. Running a series of simulations compatible with the BMcD 1% drought scenario, with limits set at both the current (1993) and proposed minimum index levels for ASR credit pumping, allows for analyzing the hydrologic effects of the three categories of pumping described above.

Hydrologic Budget Analysis

Scenario A – City Pumping 40,000 AF/y (without ASR Credit)

The pumping schedule to assess the effect of pumping without ASR credit is based on the City goal of using 40,000 acre feet per year (AF/y) from the Equus Beds wellfield (EBWF) prior to use of ASR recharge credits (Burns & McDonnell, 2018a, p. 2-5).[2] **Figure 2** shows the hydrologic system response to the City pumping 40,000 AF/y during the 1% drought scenario. In the first year of pumping, approximately 20 percent of the pumping amount (10 cfs) is depleted from the river system; by the second year, about 35 percent of the pumping amount (20 cfs) is depleted.

Scenario B – City Pumping ASR Recharge Credit to Current Minimum Index Level

The pumping schedule for diverting ASR recharge credit is based on using the model to solve for the amount of credit water that can be diverted from above the current minimum index level. The analysis is derived by running the 1% drought scenario with the City goal of diverting 40,000 AF/y and using the MNW-well capability to determine the amount of water remaining above the current minimum index levels that can also be diverted. That amount of water remaining is the ASR recharge credit water that can potentially be diverted with the City's existing ASR permit (subject to also pumping 40,000 AF/y). The analysis allows for isolating the potential ASR recharge credit water that can be diverted in the 1% drought scenario. **Figure 3** shows the quantity of that water and the hydrologic system response of pumping it. The total amount water diverted is about 14,900 acre feet, which indicates that, if the City prioritizes pumping 40,000 AFY to pumping ASR recharge credit, much of the water diverted from above the current minimum index level is to satisfy the goal of diverting 40,000 AF/y.

Scenario C – City Pumping ASR Recharge Credit to Proposed Minimum Index Level

Analyzing the effect of the Proposal (Scenario C) is similar to Scenario B, except the limit on the minimum index level in the MNW wells is lowered from the current permitted level to the proposed level. The analysis identifies the potential ASR recharge credit that could be diverted if

[2] This is similar to the BMcD 1% drought scenario which simulates approximately 40,000 AF/y of non-credit water diverted from the EBWF in all eight years of the drought, except the first year when 34,202 AF is diverted.

drawdown from City pumping occurred to the level of the proposed minimum index level. **Figure 4** shows the hydrologic system response to that diversion and indicates the amount of ASR recharge credit water that could produced is 79,500 acre feet, which is in addition to the 14,900 acre feet produced in Scenario B.

Discussion of Budget Analysis

The hydrologic budget analysis provides insight to system response in the context of City pumping that causes drawdown to the proposed minimum index level. Points are apparent regarding stream depletion in consideration of minimum desirable streamflow (MDS) and surface-water availability.

Minimum Desirable Streamflow

The permit that regulates the City's ASR project restricts the recovery of recharge credits to periods when water levels are above the established minimum index level (Burns & McDonnell, 2018a, p. 1-1). The proposal seeks to revise the minimum index level to a lower elevation, which would allow a new diversion of groundwater. **Figure 4** shows the potential credit water that could be diverted results in up to 10 cubic feet per second (cfs) of depletion to the Little Arkansas and Arkansas rivers

The minimum desirable streamflow (MDS) established at the gage on the Little Arkansas at Valley Center is 20 cfs.[3] **Figure 5** shows a chart of flow at that gage during the two years (2011 and 2012) that characterize the 1% drought scenario. During that time, flow at the gage is below 20 cfs 49 percent of the time. A change in flow of 5 cfs at that gage (assuming about half of the impact occurs on the Arkansas River) during the drought, would impact MDS flow so that it is less than 20 cfs about 53 percent of the time (**Figure 5**). The percentages translate to about one month of MDS flow not met due to drawing down water levels from the current minimum index level to the proposed level.

The City wells are located in between the Little Arkansas and Arkansas rivers and analysis indicates that diversion/injection of water into the BSA affects river flow. During times when water

[3] The minimum desirable streamflow on the Little Arkansas River is 20 cfs every month of the year (K.S.A. 82a-703c.)

levels are low in the BSA, injection of credit water into the aquifer will initially fill aquifer storage and eventually add flow to the river system and to evapotranspiration. However, during times of drought, when MDS flow is generally of concern, the Proposal seeks to recover credit water from below the current minimum index level, which will cause a new depletion to the river system that impacts MDS flow.

Surface-water availability

The USGS model simulates the Little Arkansas and Arkansas rivers as a boundary condition that does not account for total streamflow. That is, if segments of the river near the City dry out or have low flow during a drought, the model does not account for it. In that setting, there is potential for the model to overestimate river depletion from pumping, which translates to an underestimation of drawdown to aquifer water levels. The situation would affect accounting of ASR recharge credit. We inspected flow on the Little Arkansas River during the drought of 2011 and 2012 and found flow was less than 1 cfs about 30 percent of the time; on the Arkansas River, flow was less than 10 cfs over 20 percent of the time. Those quantities of flow can be depleted by the City pumping 40,000 AF/y (i.e. Figure 2 shows pumping 40,000 AF/y causes 10 cfs of river depletion in the first year of pumping and 20 cfs by the second year). Accordingly, we recommend calibrating the model with a river boundary condition that accounts for routed streamflow to improve conditions represented in adjacent rivers.

Drawdown to Aquifer Water Levels and Well Impacts

Scenarios A, B and C described above provide a basis for an examination of an example City pumping condition that draws down water levels to the proposed minimum index level (i.e. diverting 40,000 AF/y and ASR recharge credit water). **Figure 6** shows drawdown from each of the scenarios at the eighth year of the drought.[4] The drawdown illustrates an example of potential water-level impacts from City pumping if the Proposal is approved. Information on local wells can be compared to the drawdown on **Figure 6** to assess potential impacts to well water columns. The total drawdown to the proposed minimum index level is the sum of drawdown from Scenarios A, B and C.

[4] On Figure 6, Scenario B shows generally less than 1 foot of drawdown in most of the BSA.

For an assessment of potential impacts to local wells, we accessed well construction information from the Water Well Completion Records (WWC5) database available from the Kansas Geological Survey (KGS).[5] We supplemented the WWC5 well data with additional well information[6] provided by the Intervenors (Ecomm, 2019). We then mapped the wells in the area of the drawdown resulting from Scenarios A, B and C and compared total drawdown to well water columns (less 10 feet)[7] to assess whether the wells could be impacted from lowering water levels to the proposed minimum index level. **Figure 7** shows 35 wells with water columns less than the total drawdown from Scenarios A, B and C indicating potential for some wells in the BSA to lose capacity to produce water as a result of City pumping that could occur if City groundwater withdrawals cause drawdown to the elevation of the proposed minimum index level. Out of the 35 wells, 29 are impacted from the City pumping 40,000 AF/y and 6 are impacted from pumping ASR recharge credit down to the minimum index level. The aquifer drawdown assessment herein represents an example City pumping scheme that causes drawdown to the proposed minimum index level. Other City pumping schemes are possible that can affect the number of impacted wells. However, the analysis herein clarifies that the overall magnitude of drawdown to the minimum index level, caused by City well diversions, exceeds the water column expected to be needed by some wells in the area.

Figure 7 shows the locations of City wells as red circles. The red circles represent the location of the well and a 660-foot buffer around the well location. We note that out of the wells potentially impacted, many of them are located at distances greater than 660 feet from the City wells. This indicates that the minimum well spacing regulation (K.A.R. 5-22-2) for domestic wells (660 feet), from other wells in a subject application, is not sufficient to provide protection from

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[5] Since 1975, drilling companies have been mandated by state legislation to provide well information that typically includes well depth and a static depth to water (http://www.kgs.ku.edu/HighPlains/data/, data accessed Jan 18, 2019). We quantified well water columns from reported depth to water and well depths in WWC5. The available data is not expected to include all area wells since wells are anticipated to have been drilled prior to 1975.

[6] The information provided for most of the Intervenor wells included a water rights number. For those wells, we cross-referenced water rights numbers with the Water Information Management and Analysis System (WIMAS) to determine well location. For wells that did not have a water rights number, we mapped the wells to the nearest section of the Public Land Survey. Most of the Intervenor wells did not have depth to water. To estimate well water columns, we cross-reference the well locations with a year 2016 digital water-level surface adapted from the USGS (https://www.sciencebase.gov/catalog/item/5824e0b9e4b0c05b678c45dd).

[7] We subtracted 10 feet from the well water columns to allow for pump submergence while the well is operating with a pumping water level. This is a general estimate that could be refined in a case-by-case setting if specific area wells are examined for impacts from groundwater pumping.

excessive drawdown, suggesting a case-by-case assessment is needed to consider impacts from City well diversions.

Water Quality Change

The USGS evaluated chloride transport in the Equus Beds aquifer in a preliminary study (Klager and others, 2014) that is based on the USGS groundwater flow model used for the analysis described herein. The USGS analysis examines pumping scenarios (and one recharge scenario) involving variations in regional and municipal pumping to develop an understanding of chloride displacement that may occur. A summary of selected USGS results is shown on **Figure 8**, which is adapted from Figure 27 of Klager and others (2014). **Figure 8** shows the greatest potential for chloride migration is located generally north of the Arkansas River along the southern portion of the BSA. Similar to the USGS technical approach, we examined chloride displacement based on the Proposal and found potential for hundreds of feet of displacement of water with chloride resulting from lowering water levels to the proposed minimum index level; the displacement is generally in the same location (southern portion of the BSA) as that of the USGS analysis. However, the USGS notes that modeled chloride in this area moved northeast at a higher rate than is observed in the field data (Klager and others, 2014, p. 72).[8] Accordingly, the modeled displacement of chloride in this area is overestimated. The USGS also reports their analysis results indicate potential for the Burrton plume to continue migrating toward the City wellfield (Klager and others, 2014, p. 72). If the City diverts groundwater resulting in lowering water levels to the proposed minimum index level, there is increased potential to induce migration of chloride from the areas of Burrton and the Arkansas River.

In the USGS study, the groundwater flow model was not altered to calibrate the solute-transport model to observed chloride concentration data (Klager and others, 2014, p. 71). The USGS indicates achieving better performance of chloride transport may require changes to the groundwater model and that future model updates will allow opportunities for that type of calibration. We agree with that assessment. In the Proposal, the City does not describe potential water quality changes associated with lowering the minimum index level. We are not familiar with the level of detail in which the City has evaluated potential water quality impacts in the context of the Proposal. Further development of the chloride displacement analysis along the line described by

[8] In the shallow part of the aquifer, the model simulated chloride movement at a rate about 2x that of observed data; in the deep aquifer, the modeled rate of movement was about 4x that of observed.

the USGS is expected to enhance the model for use in assessing potential water quality impacts. We recommend proceeding along that line in attempt to identify potential issues that may arise if drought conditions prompt the City to divert groundwater that causes drawdown to the proposed minimum index level.

PROPOSED ASR ACCOUNTING METHODOLOGY

Section 4.0 of the Proposal describes an accounting method for ASR credits. The method uses a response-function type of approach that considers a 5 percent initial loss from the BSA the first year and a 3 percent loss in subsequent years. BMcD shows that the proposed recharge accounting mirrors the current accounting approach, but with a deviation that occurs when water levels increase in the BSA.

BMcD indicates the calculation of tracking recharge credits across the BSA is a very detailed procedure requiring a substantial amount of data preparation and processing and that there is shared interest (DWR, GMD2 and the City) in developing a simplified accounting process. Accordingly, there is utility in simplifying the accounting process with a response-function type of approach. However, the USGS model accounts for the physical structure of the aquifer system and the associated change in aquifer system/river response associated with changes in water levels in the BSA. If using the USGS model is definitively too burdensome, we recommend developing a response function that accounts for both low and high water levels in attempt to improve the performance of the simplified accounting method over varying aquifer conditions. Technical coordination with BMcD would provide insight to the basis behind the proposed simplification approach and whether development of an alternative response function can provide an improved simplification technique.

SUMMARY AND CONCLUSIONS

1. The City of Wichita currently has a permit for ASR water operations that is conditioned to allow recovery of ASR recharge credit if water levels are above a specified minimum index level. The City is proposing to lower the minimum index level to allow for diverting additional ASR recharge credit that may be needed in the event of a drought.
2. On behalf of the City, BMcD developed a 1% drought simulation as a basis for the ASR Permit Modification Proposal. The analysis engine for the simulation is the USGS model of

the Equus Beds aquifer (Kelly and others, 2013). The model the City provided to GMD2 differs from the USGS model in that ratio of horizontal to vertical hydraulic conductivity is modified. We found the modification does not affect the model analysis enough to affect our overall conclusions described herein. However, unless there is a reason to deviate from the original USGS model concept, we recommend the City accounting of recharge credit and the analysis in the Proposal be updated accordingly to confirm that potentially significant factors do not arise.

3. The BMcD analysis of the 1% drought simulation presents hydrologic results in terms of general water-level elevations and percent of saturated thickness in the Basin Storage Area (BSA). The model analysis illustrates that pumping proposed during the 1% drought results in lowering about half of the water levels in the index cells of the BSA below the current minimum index level. The proposed minimum index level is lower than that derived from the model simulation. However, BMcD does not present an analysis quantifying hydrologic effects from pumping that could cause drawdown to that proposed minimum index level.
4. We present an analysis of an example scenario in which the City pumps groundwater, consistent with a goal to utilize 40,000 AF/y from its wellfield prior to use of ASR recharge credits. The scenario represents diversion of groundwater causing drawdown to the proposed minimum index level to characterize associated hydrologic effects. We also illustrate that the USGS model utility for simulation of wells includes capability for separating the hydrologic effects of City pumping non-credit water from ASR recharge credit water with consideration of the current and proposed minimum index levels. The assessment provides insight to hydrologic effects in the context of the new pumping that could occur if the minimum index levels are lowered.
5. The proximity of the City wells to the Little Arkansas and Arkansas rivers, and the aquifer properties, results in a high degree of connection between groundwater in the BSA and the rivers. In the first year of City pumping, approximately 20 percent of the pumping amount is depleted form the river system. If the City diverts ASR recharge credit water causing drawdown to the proposed minimum index level, a new depletion is anticipated to occur at the Valley Center MDS gage. Given that the Proposal is based on pumping during drought conditions, the impact is consistent with a time when MDS gage flows are a concern. The MDS flow at the Valley Center gage is 20 cfs every month of the year.
6. We recommend calibrating the USGS model with a representation of rivers that accounts for total streamflow. During drought conditions, flow on the Little Arkansas and Arkansas rivers has lowered to quantities compatible with estimated stream depletion from City

groundwater pumping. In that setting, there is potential for overestimating stream depletion, which translates to an underestimation of aquifer storage depletion. Refining the technique of modeling the rivers would improve representation of local hydrologic conditions and may translate to an improved account of ASR recharge credit.

7. We examined aquifer water-level response in the BSA from an example of City groundwater pumping that causes drawdown to the level of the proposed minimum index level. The drawdown is caused by the City pumping 40,000 AF/y in combination with diverting ASR recharge credit. The total drawdown is up to approximately 30 feet. We compared the drawdown from the scenario to information on local well water columns. The result indicates that up to 35 wells are identified with potential to lose capacity to produce water from the total drawdown. Out of the 35 wells, 29 are impacted from the City pumping 40,000 AF/y and 6 are identified to be impacted from the City diverting ASR recharge credits down to the proposed minimum index level. This observation indicates that some wells in the area can be reasonably anticipated to require a remedy associated with lowering water levels to the proposed minimum index level. Information on local well water columns is from the WWC5 database that includes records beginning in 1975. Accordingly, we anticipate the drawdown assessment does not include all of the local area wells. Some of the wells (domestic) are located greater than 660 feet from City wells indicating the minimum well spacing regulation (K.A.R 5-22-2) is not sufficient to provide protection from excessive drawdown caused by City pumping. This observation suggests a case-by-case assessment is needed to consider impacts from City well diversions.

8. Preliminary USGS study of chloride transport indicates potential for migration from the Burrton area and generally north of the Arkansas River along the southern portion of the BSA. The USGS notes that modeled chloride (along the southern portion of the BSA) moved northeast at a higher rate than is observed in the field data. If the City diverts groundwater resulting in lowering water levels to the proposed minimum index level, there is increased potential to induce migration of chloride from the areas of Burrton and the Arkansas River toward other wells in the area. The USGS chloride transport analysis was based on the existing groundwater flow model without alterations to improve performance of the solute transport model. It would be prudent to proceed with further development of the chloride displacement analysis in attempt to identify potential issues that may arise if drought conditions prompt the City to divert groundwater that causes drawdown to the proposed minimum index level.

9. The calculation of tracking recharge credits is reported to be a detailed process. The Proposal describes a response-function type of approach to simplify the accounting method. The simplified approach deviates from the current approach under conditions of high water levels. The USGS model provides the best approach for accounting. If a simplified approach is necessary, we recommend development of a response function that accounts for both low and high water levels in attempt to improve the simplified accounting method over varying aquifer conditions.

QUALIFICATIONS AND EXPERIENCE

I am a Certified Professional Hydrologist (08-HGW-1817) with the American Institute of Hydrology. I am President of Balleau Groundwater, Inc. and have over 20 years of experience in major aspects of hydrology and hydrogeology with emphasis on analysis of hydrologic processes involving the interaction of groundwater and surface-water. Development of field-testing programs, assessment of wellfield performance and yield, water-resource planning and management, arid zone hydrology, artificial recharge, mine dewatering and water rights litigation support have also been major activities.

I have developed, adapted or worked with more than 100 hydrogeologic models. My experience includes analysis of the local and regional water budgets for both natural hydrologic conditions and changes induced to the natural system from development of surface water and groundwater. I have evaluated recharge and recovery of groundwater credit water in southwestern New Mexico and peer reviewed analyses of artificial recharge in southern California. Over the past decade I have analyzed hydrologic effects in the Rattlesnake Creek Basin in the area of Stafford County, Kansas and I am one of the authors of the model currently used by KDA-DWR for analysis of hydrologic effects in the area of Groundwater Management District No 5. I have advised cities and peer reviewed hydrogeologic analyses for municipal water districts regarding water resources in settings that involve groundwater pumping, artificial aquifer recharge, aquifer recharge from flooding and remediation of groundwater contamination. I have also advised industrial water users, irrigation and conservancy districts, state and federal agencies, Indian tribes, water associations and private water users with matters involving source water availability. I have presented at conferences involving groundwater hydrology and I have been invited to publish in a Theme Issue of the peer-reviewed journal *Groundwater* on research related to analysis of groundwater flow.

I attest to the contents and substance of the above report.

AMERICAN INSTITUTE OF HYDROLOGY
Certificate Number
1817
Dave Romero
Professional Hydrologist-Ground Water

Dave M. Romero, P.H.

Date: Feb 18, 2019

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Burns & McDonnell, 2018a, ASR Permit Modification Proposal – Revised Minimum Index Levels & Aquifer Maintenance Credits: prepared for City of Wichita, Kansas, Project No. 71395, report dated: 3/12/2018.

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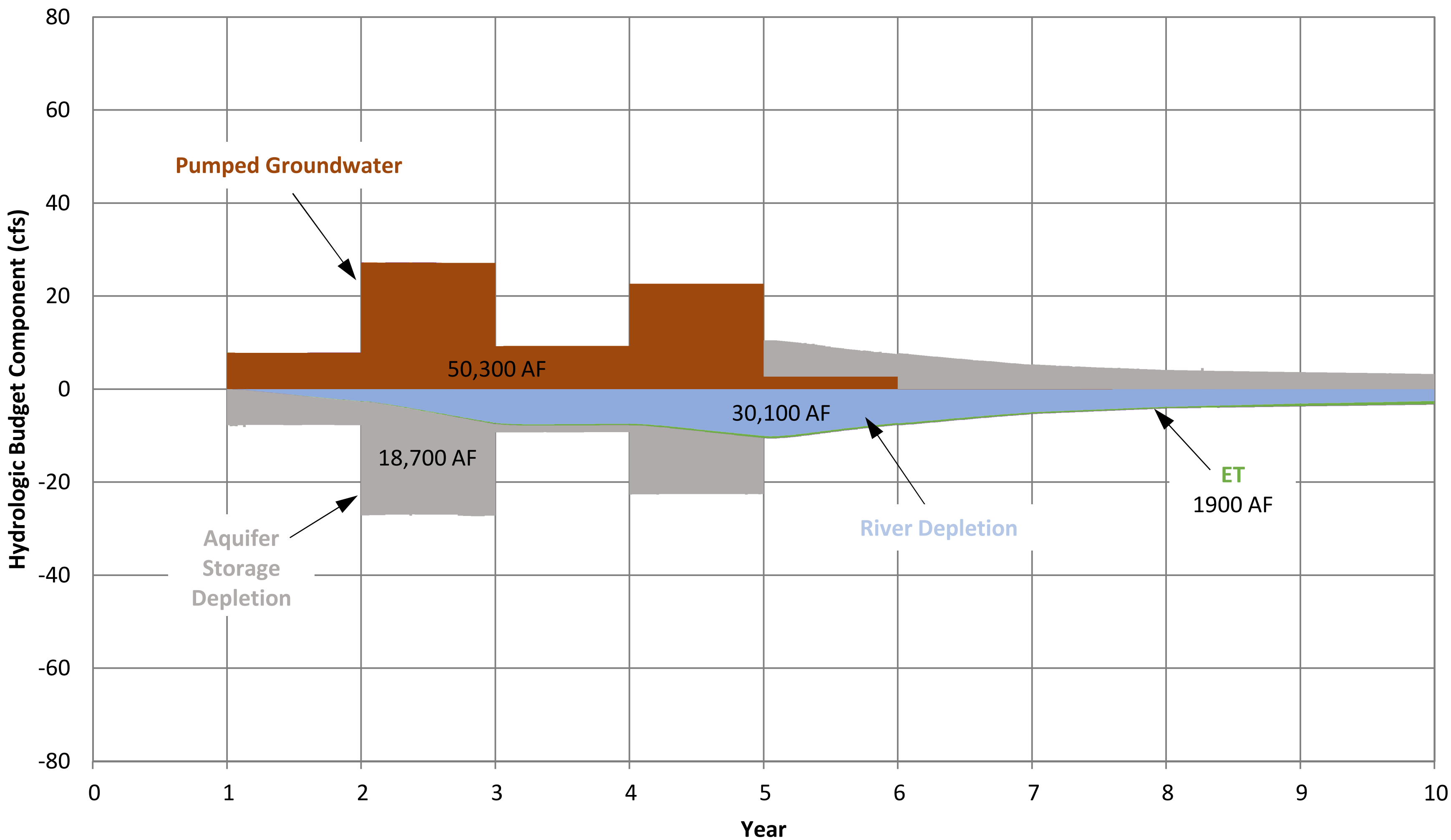
Konikow, L.F., Hornberger, G.Z., Halford, K.J., and Hanson, R.T., 2009, Revised multi-node well (MNW2) package for MODFLOW ground-water flow model: U.S. Geological Survey Techniques and Methods 6–A30.

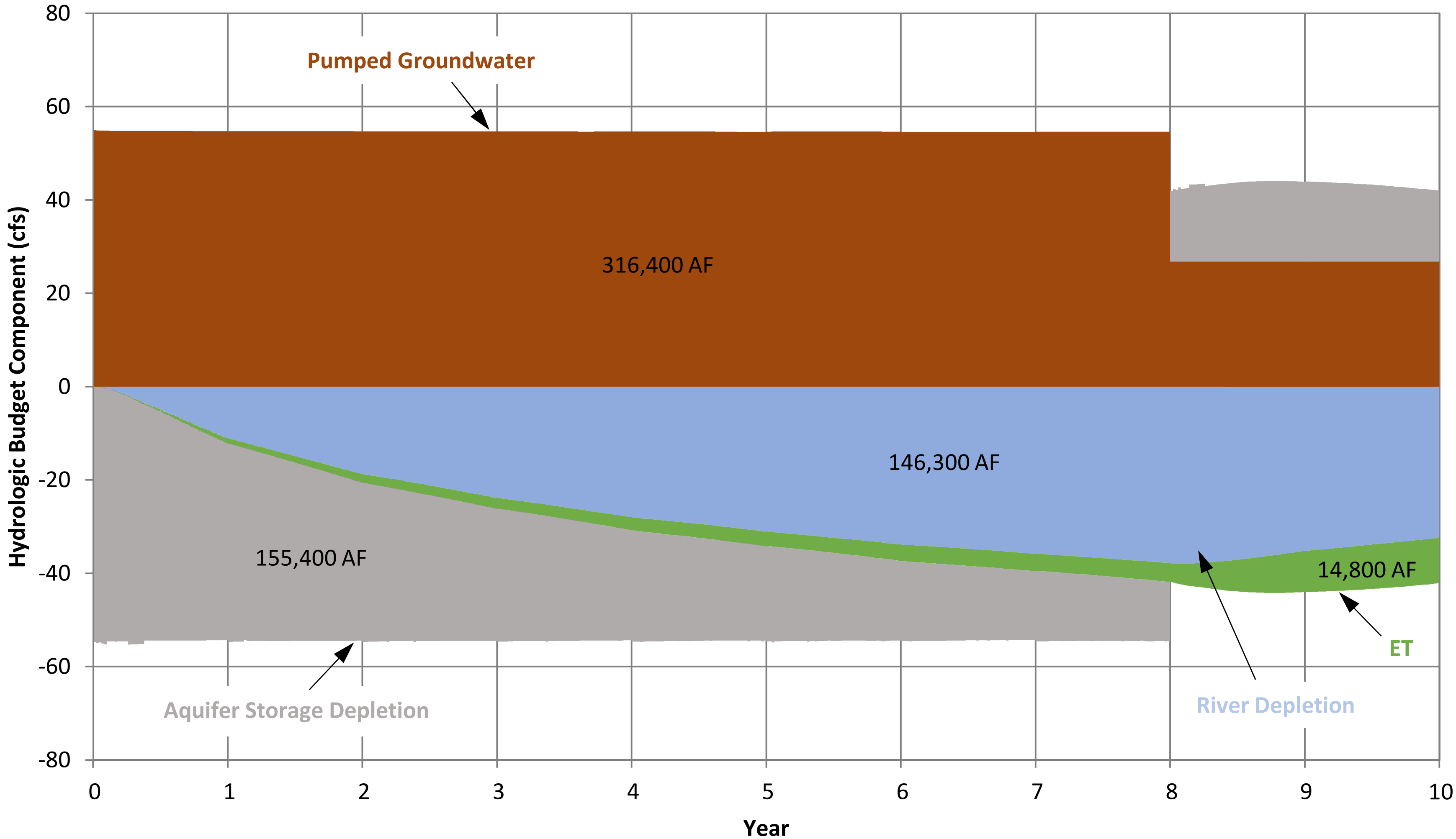
[Macey] Letter dated Sep 28, 2018 from Scott A. Macey, Water Resources Engineer with the City of Wichita Department of Public Works & Utilities to Mr. Tim Boese, District Manager of the Equus Beds Groundwater Management No.2.

FIGURE 1
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING ASR RECHARGE CREDIT



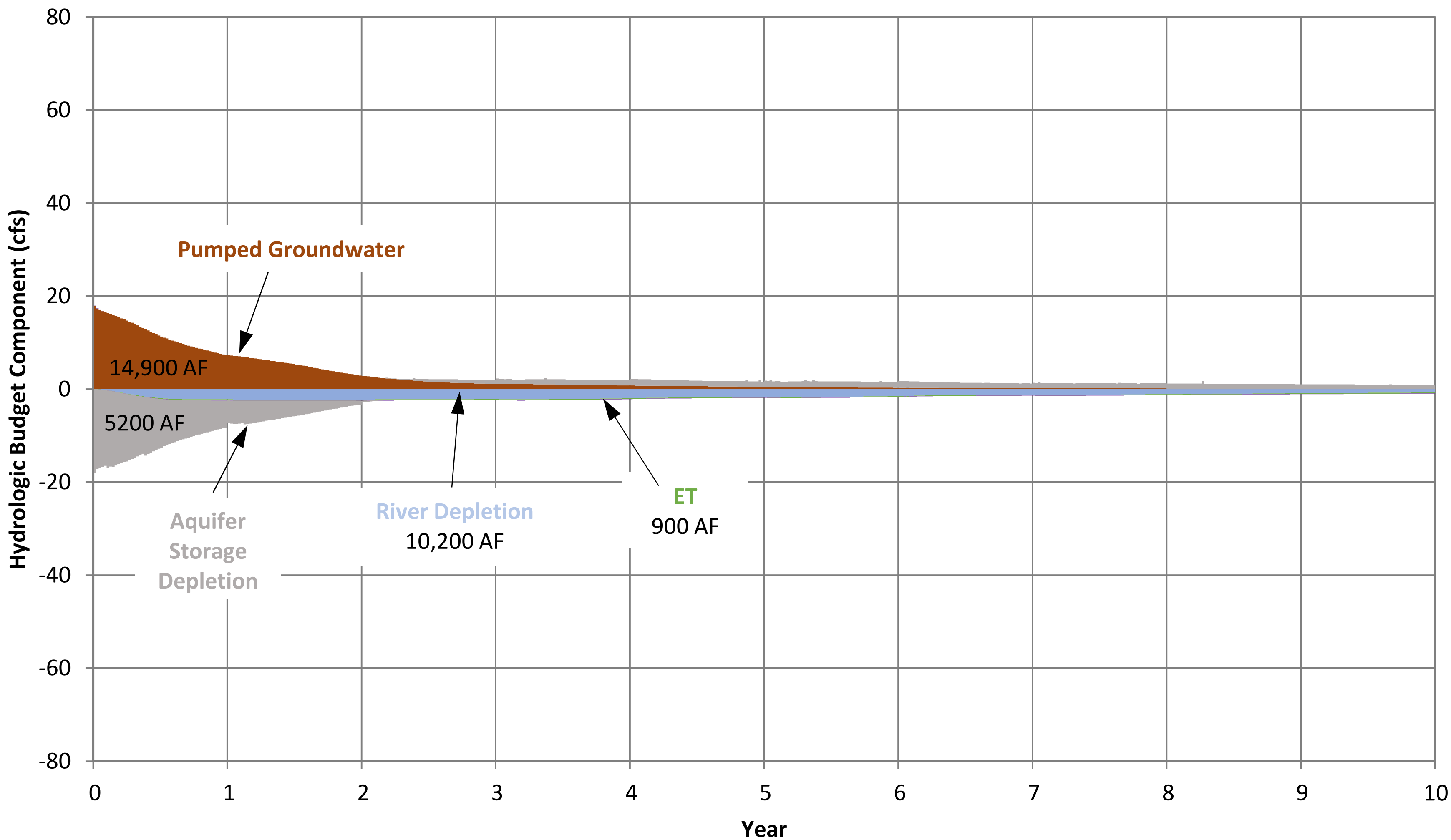
Note: Budget volumes are over 8-year period

FIGURE 2
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING 40,000 AFY (SCENARIO A)



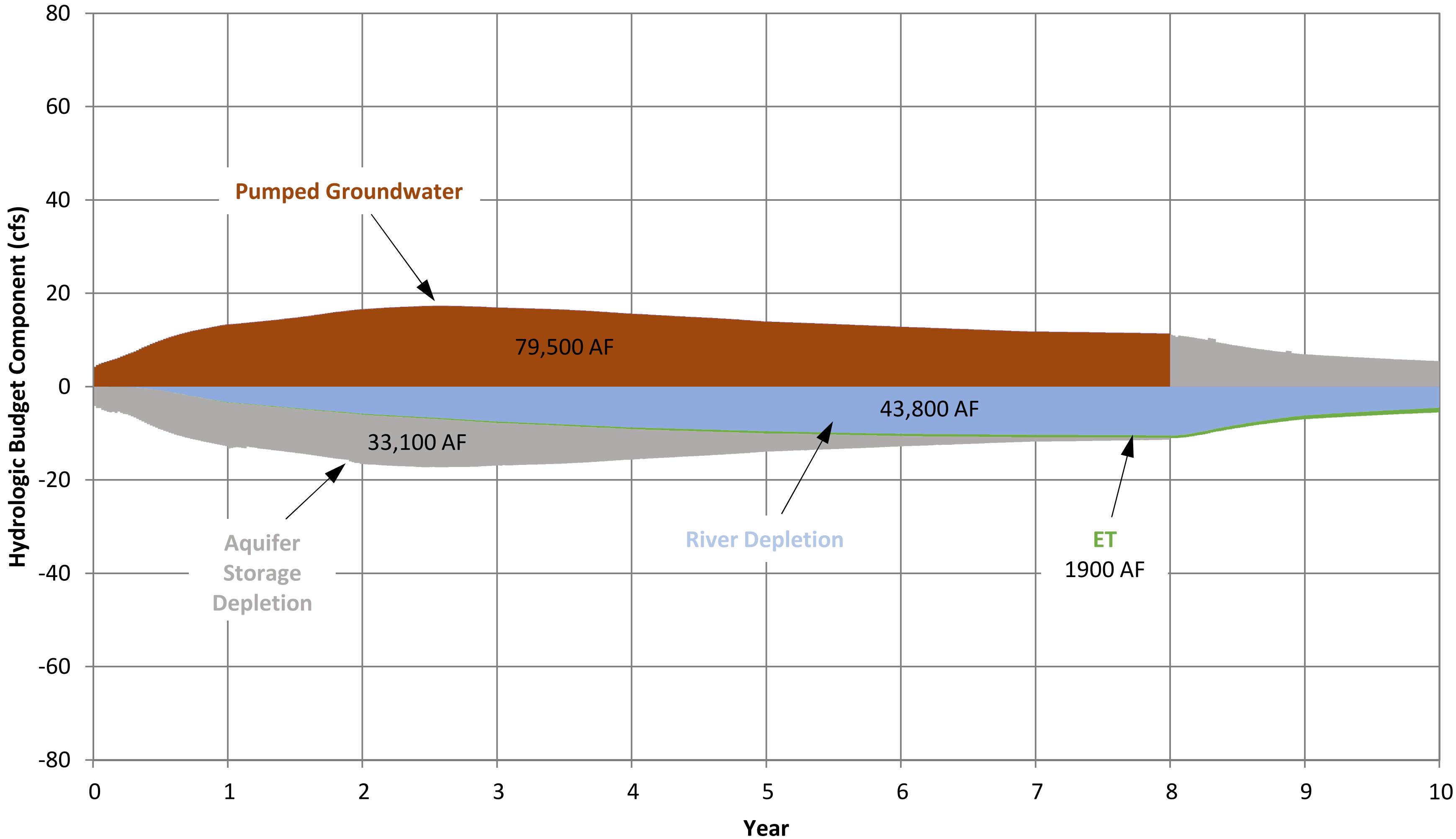
Note: Budget volumes are over 8-year period

FIGURE 3
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING PERMITTED ASR RECHARGE CREDIT (SCENARIO B)



Note: Budget volumes are over 8-year period

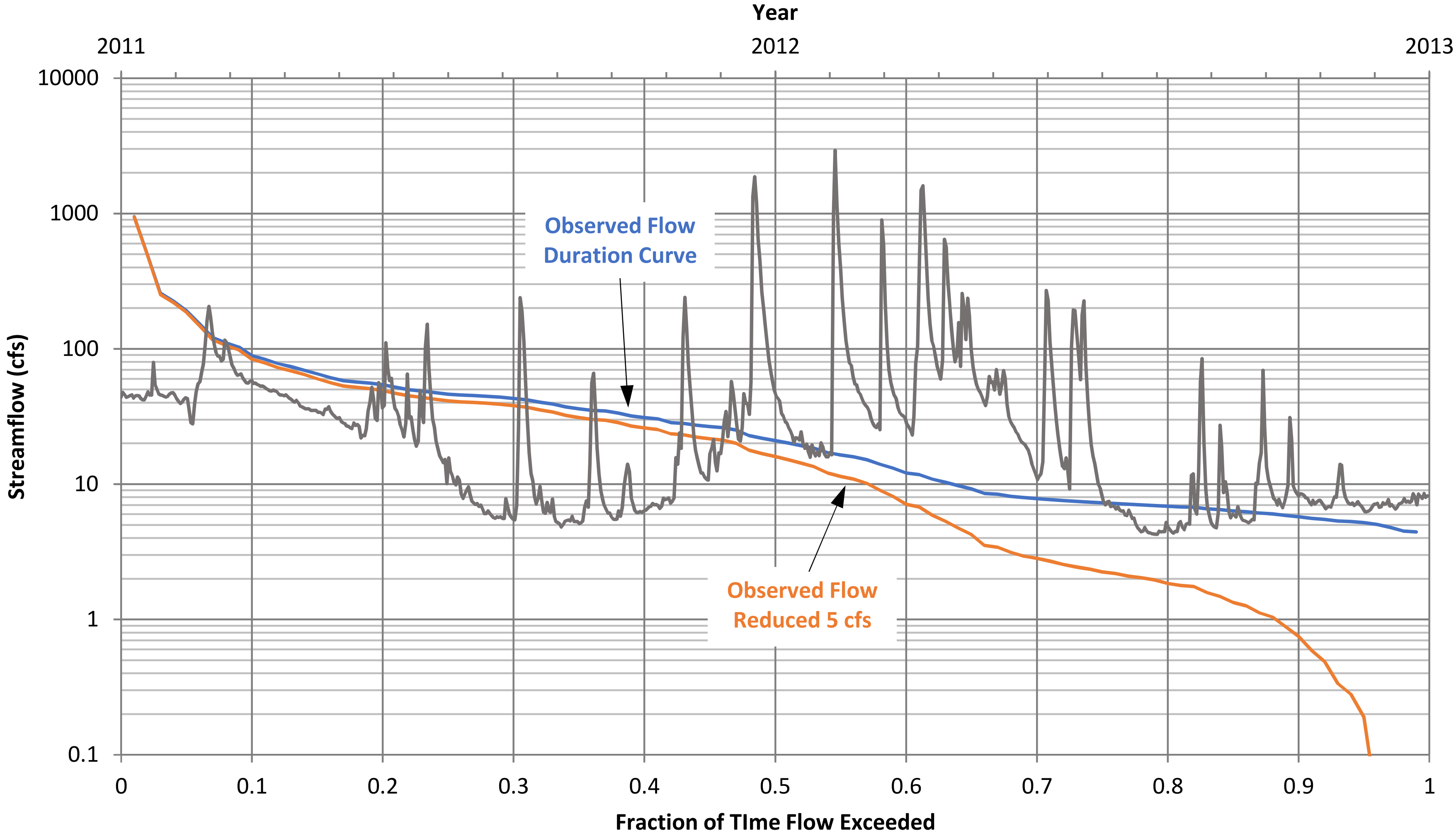
FIGURE 4
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING PROPOSED ASR RECHARGE CREDIT (SCENARIO C)



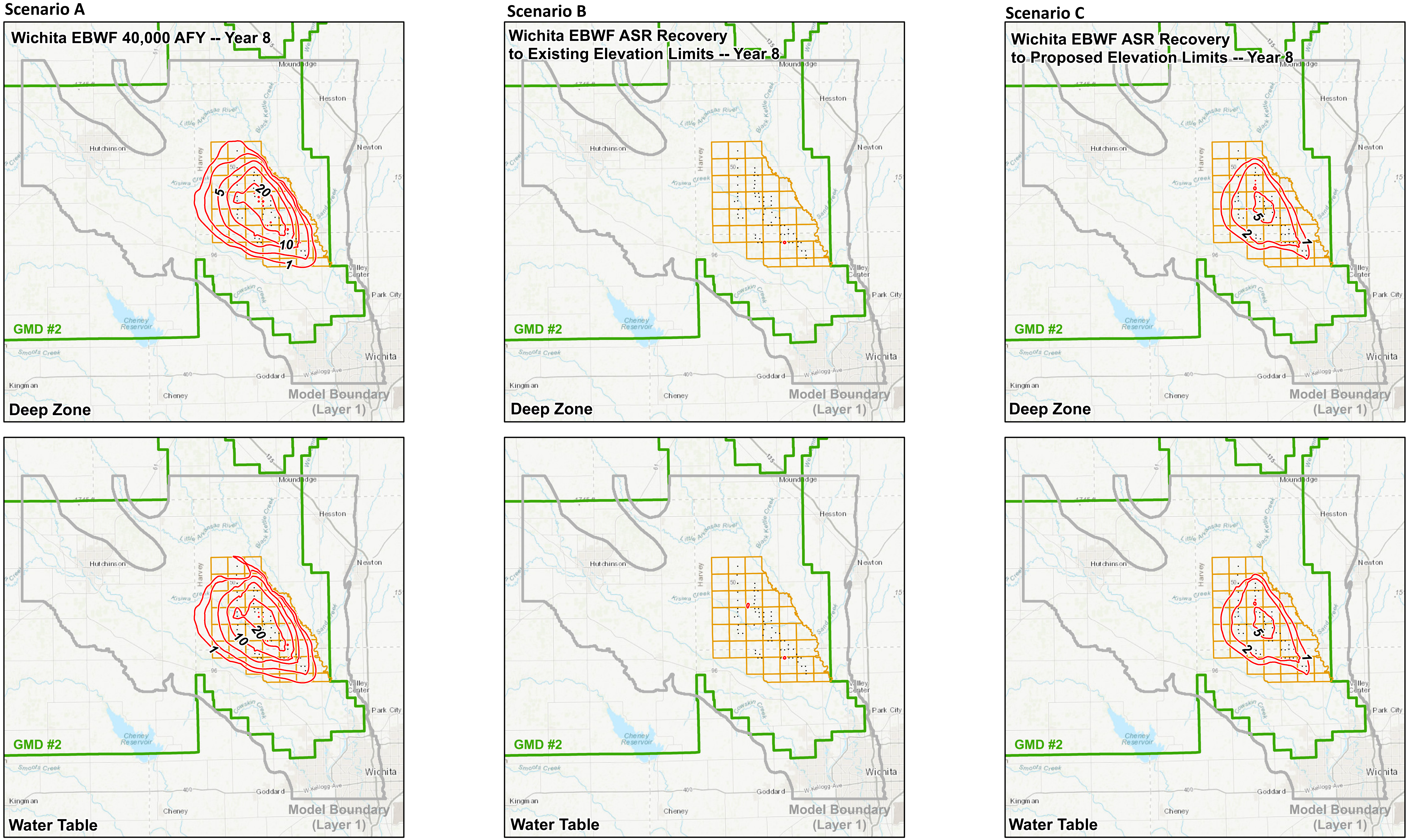
Note: Budget volumes are over 8-year period

WDMbudgets
BY
2/15/2019

FIGURE 5
FLOW ON LITTLE ARKANSAS RIVER AT VALLEY CENTER (USGS 07144200)



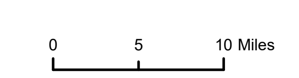
streams
BY
2/15/2019

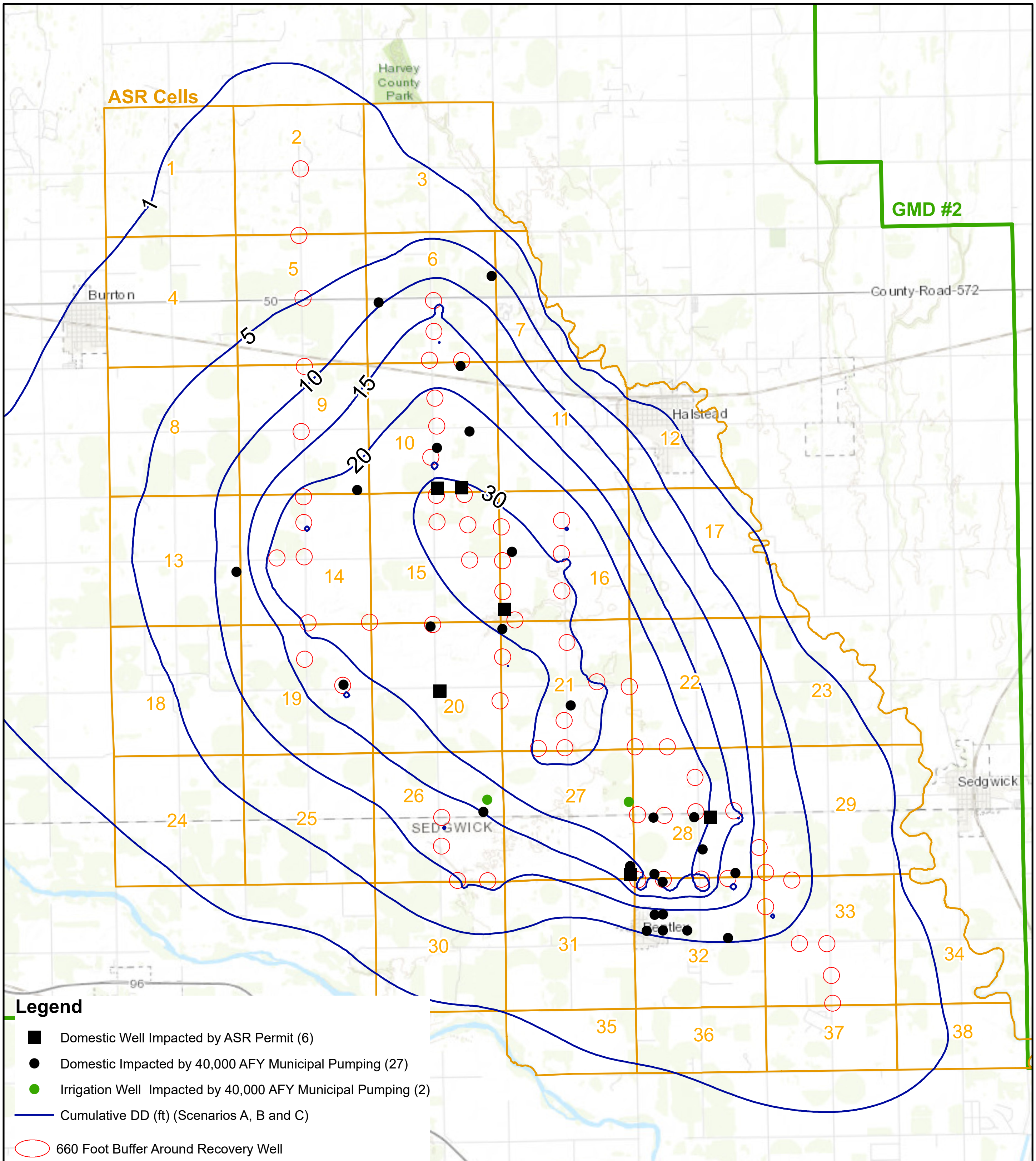


Countour interval = 1, 2, 5, 10 and 20 ft.

WATER-LEVEL DRAWDOWN FROM SCENARIOS A, B and C

FIGURE 6

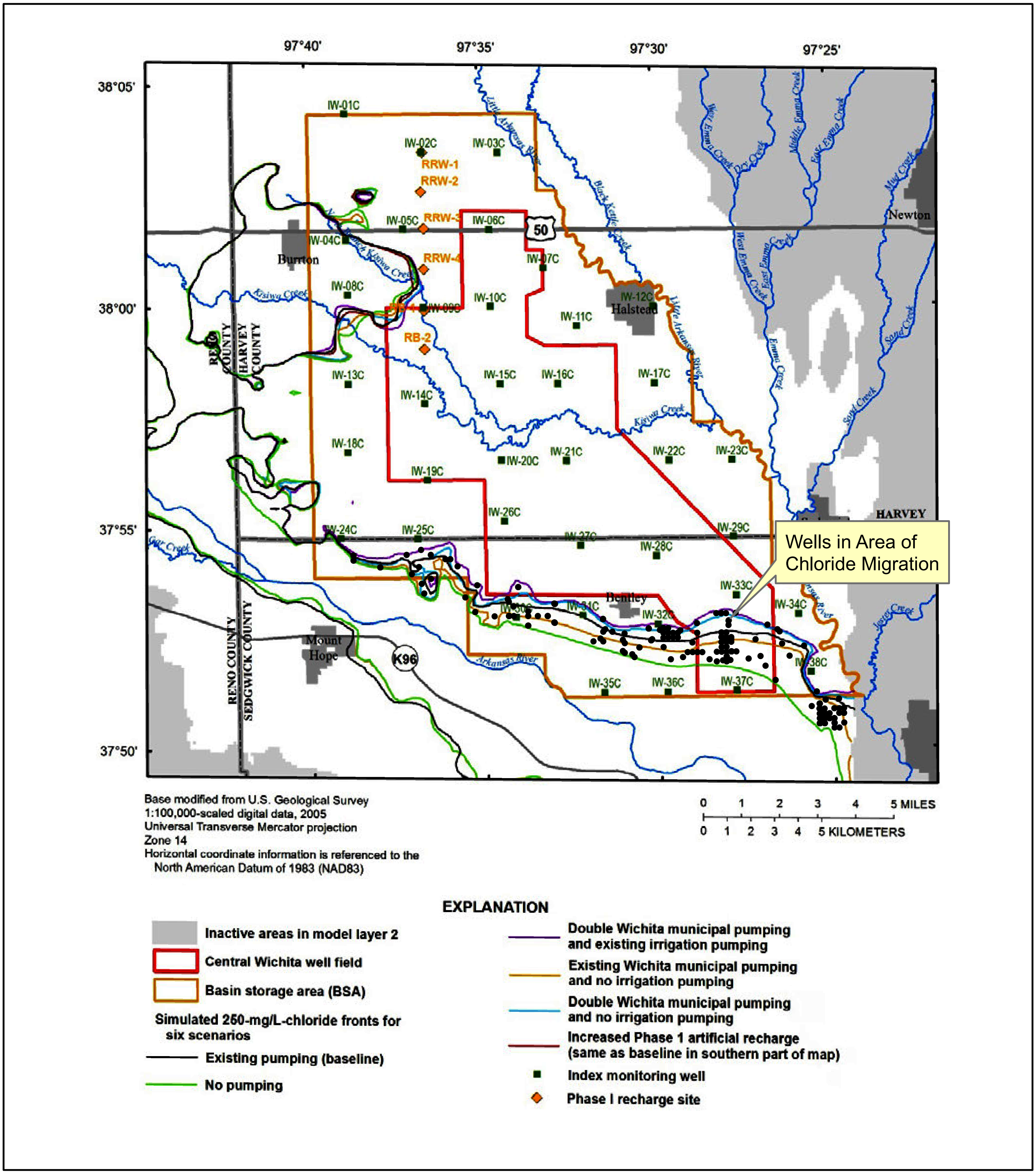




WELLS PROJECTED TO LOSE CAPACITY TO PRODUCE WATER FROM WATER-LEVEL DRAWDOWN TO PROPOSED MINIMUM INDEX LEVEL

FIGURE 7

Data Sources
Base VIA ESRI online.
Recovery wells from GMD #2 data.
Well locations from WWC5 data, accessed January 18, 2019.



ADAPTED USGS FIGURE 27
KLAGER AND OTHERS (2014)
FIGURE 8

0 0.5 1 2 Miles

Coordinate System: NAD 1983 UTM Zone 14N

City of Wichita Aquifer Storage and Recovery Proposed Modification

Hearing Before
David W. Barfield, Chief Engineer
Kansas Department of Agriculture
Division of Water Resources

Expert Report

by
David L. Pope, P. E.
Pope Consulting, LLC
3644 SW Stonybrook Dr.
Topeka, Kansas 66614

Submitted for Party
Equus Beds Groundwater Management District No. 2

February 18, 2019

Introduction

I was retained by the Equus Beds Groundwater Management District No. 2 to provide my expertise regarding the City of Wichita proposed modification of its Aquifer Storage and Recovery program. This Expert Report is provided for use during the Administrative Hearing to be held before Chief Engineer David Barfield regarding the proposed modification.

Qualifications

I hold BS and MS degrees in Agricultural Engineering from Oklahoma State University where I specialized in irrigation and water resources engineering. I am a licensed Professional Engineer in Kansas. During my career, I worked for Kansas State University as an Extension Irrigation Engineer, served as Manager of the Southwest Kansas Groundwater Management District No. 3, was Assistant Chief Engineer, and then Chief Engineer of the Kansas Department of Agriculture, Division of Water Resources (DWR) during the period 1983 through 2007. These positions involved water management, water administration and water policy issues. As Chief Engineer, I had statutory responsibility for the administration of water in Kansas, including the appropriation, regulation and distribution of surface water and groundwater, and the promulgation of rules and regulations in accordance with the Kansas Water Appropriation Act, as well as the administration of some 25 other statutes related to the conservation, management, use and control of water and watercourses in Kansas. I was also the State of Kansas official representative to each of the four interstate river compacts to which Kansas is a party. As Chief Engineer, I held numerous administrative hearings regarding water cases. I was also involved in significant litigation regarding appeals of agency decisions or enforcement actions. In several cases, I testified in court regarding the basis of the decisions and my interpretation of Kansas water law.

I was involved in two U.S. Supreme Court cases during my tenure as Chief Engineer: *Kansas v. Colorado,* No. 105, Original (Arkansas River) and *Kansas v. Nebraska and Colorado,* No. 126, Original (Republican River). I testified several times as an expert witness in the fields of Water Administration and Agricultural Engineering during various phases of the extensive *Kansas v. Colorado* trial. Regarding the Republican River, I led the team for Kansas that negotiated the Final Settlement Stipulation (FSS) to resolve the litigation over the Republican River Compact, which was reached in 2002. Since my retirement as Chief Engineer in 2007, I have operated a consulting business (Pope Consulting, LLC) with major focus on water and natural resources issues. In this capacity, among other things, I testified in two arbitration hearings for Kansas related to enforcement of the FSS, and two trial segments before the Special Master appointed by the U.S. Supreme Court. Ultimately, Kansas was very successful in obtaining compliance with both Compacts.

My Resume provides additional detail regarding my experience and education.

Summary of Report

This Expert Report provides information regarding my experience and qualifications to provide this Expert Report, background information about Phase I and Phase II of the currently authorized Wichita Aquifer Storage and Recovery Project, and a summary of the current proposal. It provides references to applicable Kansas statutes and regulations, my analysis, and conclusions and opinions.

Background

Aquifer Storage and Recovery Project, Phase I:

On July 3, 2003, the City of Wichita (City) filed a series of applications, pursuant to the provisions of the Kansas Water Appropriations Act (KWAA), proposing the appropriation of water for beneficial use to operate an Aquifer Storage and Recovery Project (ASR), in Harvey and Sedgwick Counties, Kansas. On September 14, 2004, the Equus Beds Groundwater Management District No. 2 (GMD2) and the City entered into a Memorandum of Understanding (MOU1) regarding Wichita's Proposed ASR, Phase 1. MOU1 provided various terms, conditions and commitments of the parties, including those in Attachment A, which was explicitly made a part of the Agreement. MOU1 included a recommendation of approval of the Proposed ASR by GMD2, as modified by MOU1, with the conditions referenced in the MOU. On November 19, 2004, an additional groundwater recharge credit recovery application was filed for use in the ASR.

On August 8, 2005, the Chief Engineer approved a series of applications for the appropriation of water filed by the City, including seven applications for bank storage wells, and four applications for groundwater recharge credit recovery, and issued a Findings, Conclusions and Order (Original Order), setting forth the conditions for operation of an ASR in Harvey and Sedgwick Counties, Kansas, known as Phase I of the Project. In Conclusion No. 3, the Chief Engineer indicated: "That passive recharge credits should not be allowed because they are not "artificial recharge" as defined in K.A.R. 5-1-1, because no source water is being artificially recharged to create those credits". In addition, paragraph No. 2 of the Order says: "That passive recharge credits shall not be allowed". The Chief Engineer's Findings, Conclusions and Order made numerous references to MOU1, the GMD2 recommendations regarding the ASR, and the role of GMD2 in monitoring, review and future recommendations. Pursuant to this Order, recharge credits are accumulated through metered physical recharge of source water and determined using an annual accounting model and report.

On August 1, 2006, in a Findings and Order (Modified Order), the Chief Engineer modified the Original Order for the ASR, specifically permit conditions Nos. 9, 12, 14, 17, 20, and 23, pertinent to bank storage wells.

On October 10, 2006, the City filed a new surface water diversion application to replace four of the bank storage well permits. The Chief Engineer approved the application on February 19, 2007, and at the request of the City, also dismissed four of the bank storage well permits. On February 4, 2010, the Chief Engineer approved an additional groundwater recharge recovery application.

According to the Chief Engineer David Barfield's presentation at a public information meeting on June 28, 2018, Phase I of the ASR: "allows recharge of treated Little Arkansas River surface water and bank storage wells to develop recharge credits and slow the migration of salt water contamination moving toward the wellfield from the Burton area. The Phase I permits allow recharge up to 10 million gallons per day (MGD). It includes five recharge recovery permits."

Aquifer Storage and Recovery Project, Phase II:

On November 13, 2006, File No. 46,627 was filed proposing the appropriation of surface water from the Little Arkansas River for the ASR. It was authorized to divert 45,230 acre-feet per year at a rate of 41,667 gallons per minute. On February 12, 2007 and October 8, 2008, respectively, the City filed an additional series of applications proposing the appropriation of groundwater for the ASR.

On December 3, 2008, the City and GMD2 signed a second Memorandum of Understanding (MOU2) regarding the City's Proposed ASR, Phase II. MOU2 provides background information, and in Part A, identified eight issues and the commitments of the parties to resolve the issues on various terms and conditions. Part B of MOU2 provides criteria for a potential recommendation by GMD2 to waive its spacing regulations for certain ASR water permit applications filed by the City under certain circumstances. It further provides that commitments in MOU2 are subject to the requirements of state law, regulations and orders of the Chief Engineer, and that at intervals of no more than five (5) years, the City and GMD2 will jointly assess the need to continue any and all provisions of the MOU.

On September 18, 2009, the Chief Engineer approved a series of applications for the appropriation of water filed by the City, including one for a surface water diversion and twenty-four for groundwater recharge recovery credit to operate Phase II of the ASR Project, and issued a "Findings and Order", setting forth the conditions of the approval. Finding No. 6 provides: "That aquifer storage and recovery means the artificial recharge, storage and recovery of water and consists of apparatus for the diversion, treatment, recharge, storage, extraction and distribution of water". Paragraph No. 11A of the Findings and Paragraph No. 2 of the Order both provide: "That passive recharge credits shall not be allowed". Additionally, on September 28, 2010, the Chief Engineer approved six additional groundwater recharge credit recovery permits. Pursuant to this Findings and Order, recharge credits are accumulated through metered physical recharge of source water and determined using an annual accounting model and report.

According to the Chief Engineer Barfield's presentation at a public information meeting on June 28, 2018, Phase II of the ASR: "allows the recharge of treated Little Arkansas River surface water into the Equus Beds well field to accumulate recharge credits for subsequent use by the City. Phase II is designed to permit recharge of up to 30 million gallons per day. It includes 30 recharge recovery permits."

Current Proposal:

On July 23, 2013, the City of Wichita (City) filed 30 new applications to appropriate water, File No's 48,704 through 48,733. The purpose of these applications was to authorize the recovery of aquifer recharge credits from the City's existing municipal supply wells."

On March 12, 2018, the City of Wichita (City) submitted a letter to the Chief Engineer, along with an ASR Permit Modification Proposal and supportive information prepared by the Burns & McDonnell Engineering Company, Inc. In summary, the City requested that the Chief Engineer, without filing any other new or change applications, do two things:

(1) Revise and lower the minimum index levels used to determine when the City may withdraw its Physical Recharge Credits (PRCs), and

(2) Authorize the City to use a new type of recharge credit from project operations, called Aquifer Maintenance Credits (AMC), for diverting surface water from the Little Arkansas River during times when recharge capacity in the Equus Beds Aquifer was limited, and sending it directly to the City for use. The City proposed that instead of injecting the treated water into the Aquifer, it would receive this new type of AMC credit by offsetting it through reduced Equus Beds groundwater pumping, although it appears that no specific condition is proposed to require or guarantee the reduction in groundwater pumping.

On March 22, 2018, Chief Engineer Barfield provided detailed comments regarding the City of Wichita ASR Project in a letter to GMD2 and the City, which included an attached "Initial Draft for review, March 22, 2018 Proposed Replacement F & O for ASR Phase II, an attached "Draft for initial review, March 22, 2018 Example proposed individual approval for one of the new applications, and a "Draft for initial review, March 22, 2018 Example Proposed F & O amending terms & conditions of an existing ASR Phase II permit". Chief Engineer Barfield offered to discuss these specific conditions and meet with the GMD2 board to discuss these matters, if desired.

By letter dated April 27, 2018 to Chief Engineer David W. Barfield, GMD2 indicated that the Board of Directors had reviewed the draft proposed conditions regarding the Wichita ASR project, and decided to forward comments and questions, including Attachments A through D, to the Chief Engineer for his consideration.

By letter dated June 1, 2018, the Chief Engineer responded to the comments and questions from GMD2 regarding the its initial review of the City's proposed changes to its ASR program. The letter indicates that "...with the inclusion of proper terms, conditions and limitations, an accounting method which creates the functional equivalence of aquifer recharge could be implemented". The letter also indicates "As envisioned, AMCs should serve the public interest by facilitating fuller aquifer conditions without allowing the use of new or unappropriated water". Additional responses to GMD2 questions were provided with an attachment to the letter.

On June 28, 2018, Chief Engineer Barfield held a Public Information Meeting regarding the Wichita ASR proposal in Halstead, Kansas. According to his presentation, and other information posted on his agency website, he outlined a draft proposal for public consideration of potential action on the City's proposal:

> 1. (the) **lower minimum index cell levels** ...will be changed to those indicated in the City's proposal. (The Chief Engineer noted that as an example for the ASR recharge recovery permit located in Index Cell No. 6, it is proposed to lower the minimum index cell level from about 1,388.74 feet to about 1,370 feet msl).
> 2. **Physical recharge activities will continue** to occur when there is adequate recharge capacity within the aquifer.
> 3. **The AMCs may be accumulated only when** index water levels are at elevations that limit physical recharge into the [Basin Storage Area] BSA as provided in the [Aquifer Storage and Recovery's] ASR's operating plan." (See Burns and McDonnel report at 3-6 to 3-10) If the recharge capacity, based on infrastructure and static water level in the aquifer in January, is below 5 percent, all credits are AMCs. If the recharge capacity is above 5 percent, water diverted from Little Arkansas will be physically recharged up to aquifer capacity limits, then the rest will be AMCs.
> 4. **The AMC accumulation rate** will be dependent on the **quantity of water treated and sent to the City** within the authorization of File No. 46,627.
> 5. .... A one-time five percent (5%) initial loss will be deducted from the total number of AMCs applied in each index cell. In addition, a recurring loss to AMCs, ... would be applied annually...to account for the migration of recharge credits and losses from the BSA as illustrated by the model and historic data.
> 6. The **total accumulation of recharge credits** through the PRCs and AMCs combined cannot exceed **120,000 acre-feet**, which represents the documented amount of aquifer storage available within the ASR project area in 1993."

(Emphasis in original).

On September 20, 2018, the City requested that the Chief Engineer dismiss the 30 new applications to appropriate water, File No's 48,704 through 48,733. On October 2, 2018, the Chief Engineer entered an order dismissing those applications.

According to DWR records, the City holds existing water rights to divert up to a total of 40,000 acre-feet per calendar year from its Equus Beds Aquifer well field (EBWF) for municipal use in the City of Wichita and surrounding areas within the authorized place of use. According to the Burns and McDonnell (BMcD) report submitted to the Chief Engineer for the Proposed ASR, BMcD evaluated the viability of existing and planned raw water sources versus demands of 81,690 acre-feet (AF) by the year 2060 using a MODSIM-DSS model. Using this model, BMcD simulated how the raw water demands during a 1% drought should be distributed between Cheney Reservoir, the EBWF, and ASR system, including the use of AMCs. According to Table 2-3 of the BMcD report, City demand assigned to the EBWF & ASR during the 1% simulated drought would range from 34,202 AF in year 1 to a high of 59,907 AF in year 3. The total of these EBWF & ASR demands for the 8-year simulated drought illustrated in Table 2-3 would be 363,850 AF, or 43,850 AF more than authorized by the City's EBWF.

Statutes and Regulations

The Chief Engineer is authorized to "enforce and administer the laws of this state pertaining to the beneficial use of water and shall control, conserve regulate, allot and aid in the distribution of the water resources of this state for the benefits and beneficial uses of all of its inhabitants in accordance with the rights of priority of appropriation." K.S.A. 82a-706. The Chief Engineer is further authorized to "adopt, amend, promulgate, and enforce such reasonable rules, regulations, and standards necessary for the discharge of his or her duties and for the achievement of the purposes of this act pertaining to the control, conservation, regulation, allotment, and distribution of the water resources of the state. K.S.A. 82a-706a.

It was pursuant to this authority that the Chief Engineer adopted regulations authorizing Aquifer Storage and Recovery Permitting. *See* K.A.R. 5-12-1 through K.A.R. 5-12-4. The Chief Engineer also adopted regulations recommended by the Equus Beds Groundwater Management District, pertaining to ASR projects. *See* K.A.R. 5-22-1, 5-22-10 and 5-22-17.

In accordance with the Kansas Water Appropriations Act (KWAA) and the ASR regulations, the Chief Engineer issued the original approvals for Wichita to operate its Phase I and Phase II of its ASR.

KSA 82a-708b provides the sole legal authority for making changes to any existing water right:

(a) Any owner of a water right may change the place of use, point of diversion or the use made of the water, provided such **owner shall**:

(1) Apply in writing to the chief engineer for approval of such proposed change,
(2) Demonstrate to the chief engineer that any proposed change is reasonable and will not impair existing rights.

(3) Demonstrate to the chief engineer that any proposed change relates to the same local source of supply as that to which the water right relates.
(4) …The chief engineer shall approve or reject the application for change in accordance with the provisions and procedures prescribed for processing original applications to appropriate water….

(emphasis added).

If a water right is to be changed pursuant to K.S.A. 82a-708b, the provisions for processing a new application to appropriate water, found at K.S.A. 82a-708a, 82a-709 through 714, and the accompanying regulations, must also be followed.

Among other things, K.S.A. 82a-711 (a) provides that, "If a proposed use neither impairs a use under an existing water right nor prejudicially and unreasonably affects the public interest, the chief engineer shall approve all applications for such use made in good faith in proper form which contemplate the utilization of water for beneficial purposes, within reasonable limitations….) (Emphasis supplied).

Subsection (b) provides that: "In ascertaining whether a proposed use will prejudicially and unreasonably affect the public interest, the chief engineer shall take into consideration" five factors, including: …

(2) the area, safe yield and recharge of the appropriate water supply;

(3) the priority of existing claims of all persons to use the water of the appropriate water supply; …

(5) all other matters pertaining to such question."

Subsection (d) further elaborates, "With regard to whether a proposed use will impair a use under an existing water right, impairment shall include the unreasonable raising and lowering of the static water level…"

So, by combining the provisions of K.S.A. 82a-708b and K.S.A. 82a-711, if a water right owner proposes a change to an existing water right, the burden is on the owner of the water right to demonstrate to the chief engineer that the proposed change:

(1) Is reasonable,
(2) Will not impair existing water rights [meaning all water rights, permits, and applications with a priority date senior to the change application (senior water rights) not just those senior to the original priority],
(3) Will not prejudicially and unreasonably affect the public interest, and
(4) Will not cause an unreasonable raising and lowering of the static water level.

Analysis

In Kansas, once a water right is acquired, the only three attributes of a water right that may be changed are the: (1) authorized point of diversion, (2) the authorized place of use, and (3) the use made of the water. K.S.A. 82a-708b. Otherwise no other changes to a water right are expressly authorized by the KWAA. This requirement is there to prevent any change in the operation of a given water right to the detriment of all other water rights, permits and applications in existence at the time of the change application (senior water rights). The City is not directly proposing a change in the point of diversion, place of use or use made of the water, so arguably no change application is necessary, but the AMC program the City is proposing will have the effect of allowing the City to increase its consumption under its water rights without filing either a new or change application. This is something that could not be done if the City filed a change application, so it stands to reason that it is unlawful to do so without filing a change application. Any change in the operation of an existing water right cannot impair a water right in existence at the time the change is requested. K.S.A. 82a-708b(a)(2).

Modifications can be made to existing water rights without the filing of a change application, but such modifications are usually to correct errors, like obtaining better information as to where a well or place of use is actually located, or correcting typos, but none of these types of modifications allow expansion of a water right. The source of supply cannot be changed. The maximum annual quantity cannot be increased, and the consumptive use cannot be increased, as further described below. The priority date cannot be changed.

The ASR program, as authorized in Phases I and II, was designed to allow the City to take actual physical water from the Little Arkansas River, treat it, and inject it into the Equus Beds Aquifer. The City was then authorized to withdraw the physical recharge water it actually put in storage, subject to the annual accounting report approved by the Chief Engineer, and divert it to the City. This is consistent with the KWAA and its regulations. Generally, throughout the western United States, including Kansas, water right owners are allowed to divert and store water in reservoirs, usually surface reservoirs, and later divert it from the reservoir for later use. See K.A.R. 5-6-1 through 5-6-11. Kansas law also provides that, "Any person may conduct water into and along any of the natural streams or channels of the state, and may withdraw all such waters so by him turned into such channel at any point desired, without regard to prior appropriations of water from said stream, due allowance being made for evaporation and seepage." K.S.A. 42-303. In Kansas, a water right owner may divert surface water, particularly at a time of surplus, store it, and then release it into a stream or river to convey it to another site where it would again be diverted, except for losses, and used by the water right owner.

Phase I and II of the ASR program were authorized with exactly those principles in mind. *See* K.A.R. 5-12-1 through 5-12-4. The ASR regulations are clearly based on having a water right owner deposit real physical water into an aquifer, and not get fictional credits to later divert water from the aquifer for delivering surface water directly to the City.

In Kansas neither the KWAA nor any of the regulations adopted pursuant to it, expressly authorize the use or concept of AMCs. Phases I and II of the City's ASR program authorize diversion of surface water from the Little Arkansas River, treating and storing it in the Equus Beds Aquifer, and later diverting it by means of wells used for municipal use by the City. Under this scenario, the City never loses control of its water (except through losses as determined by the annual accounting report) and is allowed to continue to use the stored water until it loses control of it after being used for municipal purposes.

Further, it has been a bedrock principle of Kansas water law that once a permit is granted, no changes may be made to it that would expand the quantity of water diverted or the quantity of water consumed. "The extent of consumptive use shall not be increased substantially after a vested right has been determined or the time allowed in which to perfect the water right has expired, including any authorized extension of time to perfect the water right." *See* K.A.R. 5-5-3.

By way of comparison, Kansas regulations also prohibit material expansion of the authorized place of use for irrigation. Expanding the authorized place of use for irrigation would allow the water right owner to consistently apply a higher percentage of his or her water right more frequently than they would have been able to do had the place of use not been expanded. Consequently, a Kansas regulation provides generally that an application to increase an irrigation place of use may not be enlarged significantly. *See* K.A.R. 5-5-11.

What the City is proposing to do to accumulate AMCs is to divert surface water from the Little Arkansas River, treat it and send it directly to the City for municipal use. Thereby, by use of AMCs, get permission from the Chief Engineer to later divert water from the Equus Beds Aquifer that the City never put there in the first place. The water the City is asking to divert is the native water present in the Aquifer, which is there as a result of recharge from precipitation and the required return flow from other water rights in the area. To divert such native water, the City is required to file new applications to divert native water from the Equus Beds. Those applications diverting water are subject to the GMD2 regulations requiring new applications to meet the safe yield regulations of the District. K.A.R. 5-22-7. To allow the City to divert such water without filing new applications to appropriate the native water in the Equus Beds Aquifer, undermines the entire process for permitting water rights in the areas. If the proposed AMC program is approved, the City will not be diverting fictitious water, or even water it had artificially recharged, it will be diverting native water which other water right owners have a priority to divert.

While the use of AMCs has not been authorized by Kansas law, the Kansas Legislature has passed laws in recent years to provide more flexibility in how water right holders can use their water rights, but in a manner that also conserves water. Two examples that may or may not be workable for the City: K.S.A 82a-745, allows one or more water right holders in a designated area to enter into a consent agreement and order with the Chief Engineer to establish a Water Conservation Area, and develop a management plan with considerable flexibility. A second tool is provided by K.S.A. 82a-736 regarding the use of Multi-year flex accounts. These statutes illustrate that some flexibility in how water rights may be exercised has been authorized by law under some circumstances, especially where water conservation is needed and adverse impacts to other water rights will not occur.

The proposed use of AMCs, and an accounting system that treats them as a "functional equivalent of existing recharge credits", has many implications. For example, in normal administration of water rights in Kansas, water not pumped during a given calendar year cannot be pumped in a later year, except under specific circumstances authorized by Kansas law, as noted in the preceding paragraph. These statutes require various conditions to not only provide flexibility for the use of water within a defined time period, but also require the conservation of water to help deal with specific problems, such as declining aquifer water conditions. With the proposed use of AMCs, physical artificial recharge does not occur. The AMC process is proposed to occur during periods of high groundwater levels, generally associated with higher natural recharge during wetter periods, and the associated lower water use during such periods. However, the accumulation of AMCs during these periods would then allow them to be withdrawn from the aquifer during periods of drought, such as the 1% chance drought described in the BMcD report. As noted by my comments in the "Current Proposal" section of this report, this would allow a substantially larger amount of groundwater to be pumped from the aquifer using the EBWF water rights and AMC credits during such a drought when demand for water from all uses will be higher than normal.

While it may generally be in the public interest to maintain a higher groundwater level during periods of non-drought, the proposed use of AMCs and lower levels for Index wells, that causes much lower groundwater levels during periods of drought when the availability of water is most critical, would be adverse to the public interest.

It has been well established by various analytical methods, such as by a hydrological model that considers impacts on a hydraulically connected stream aquifer system, that groundwater pumping causes stream depletions to occur. This may include lag effects to the stream over extended periods of time. As a result, additional groundwater pumping impacts to the Little Arkansas River may be a significant concern during a period of drought.

Conclusions and Opinions

1. Based on my experience with administration of Kansas Water Law and Regulations, the City of Wichita ASR Aquifer Maintenance Credit proposal does not appear to be consistent with the provisions of the KWAA, K.S.A 82a-701 *et seq.* nor the regulations promulgated thereunder: K.A.R. 5-1-1, 5-12-1 through 5-12-4, K.A.R. 5-22-1, 5-22-10 and 5-22-17.

2. The proposed use of Aquifer Maintenance Credits (AMC) is a form of "Passive Recharge Credits", which are not authorized by the KWAA. They are not allowed by the Chief Engineer's ASR rules and regulations, because:
   a) K.A.R. 5-12-1(a) provides that "An operator may store water in an aquifer storage and recovery system under a permit to appropriate water for artificial recharge if the water appropriated is source water;"
   b) K.A.R. 5-1-1 (g) defines "Artificial recharge" as: "the use of source water to artificially replenish the water supply in an aquifer;"
   c) K.A.R. 5-1-1(yyy) defines "Source water" as: "water used for artificial recharge that meets the following conditions: (1) Is available for appropriation for beneficial use; (2) is above-base flow stage in the stream; (3) is not needed to satisfy minimum desirable streamflow requirements; and (4) will not degrade the ambient groundwater quality in the basin storage area;"
   d) K.A.R. 5-1-1 (mmm) defines "Recharge credit" as: "the quantity of water that is stored in the basin storage area and that is available for subsequent appropriation for beneficial use by the operator of the aquifer storage and recovery system."

Clearly, AMCs do not meet this definition of Source Water. In particular, the definition of source water does not include an offset for water **not pumped** from the aquifer, as proposed by the Wichita ASR.

3. Passive Recharge Credits are prohibited by the Orders issued by the Chief Engineer approving Phase I and Phase II of the City's ASR program. If the ASR Project is not adding physical recharge, then the AMCs, that allow credits for not pumping City wells in the basin storage area, are passive recharge that should not be allowed.

4. The concept of a "functionally equivalent method" to accumulate and account for recharge credits would not be in the public interest and should not be allowed, due to the potential adverse impacts to the aquifer and other water right holders, especially during periods of extensive drought.

5. The BMcD report illustrates that the City demand assigned to the EBWF & ASR during the 1% simulated drought could reach as high as 59,907 AF in some years, which is significantly more than the 40,000 acre-feet per year authorized by the City's EBWF. The total of these EBWF & ASR demands for the 8-year simulated drought illustrated in Table 2-3 would be 363,850 AF, or 43,850 AF more for the period than the water rights authorized by the City's EBWF (320,000 AF in eight years). If the ASR credits are not based on Physical Recharge Credits, over time, and especially during an extended drought, accumulation of recharge credits by the City through the proposed ASR by Physical Recharge Credits and AMCs combined could reach an amount that would adversely affect the ability of other water users to exercise their water rights.

6. The Wichita ASR proposal should not be approved in its current form.

List of Documents reviewed and relied upon for this report

1. The Kansas Water Appropriations Act, K.S.A 82a-701 et seq.
2. Rules and Regulations promulgated by the Chief Engineer pursuant to the Kansas Water Appropriations Act.
3. The Kansas Groundwater Management Districts Act, K.S.A 82a-1020 et seq.
4. Rules and Regulations adopted by the Chief Engineer for the Equus Beds Groundwater Management District No. 2 pursuant to recommendations of the District.
5. Memorandum of Understanding between Equus Beds Groundwater Management District No. 2 and the City of Wichita, effective September 9, 2004.
6. Findings, Conclusions and Order (Phase I, Original Order) issued by Chief Engineer David L. Pope on August 8, 2005.
7. Memorandum of Understanding between Equus Beds Groundwater Management District No. 2 and the City of Wichita, effective December 3, 2008.
8. Findings and Order (Phase II) issued by Chief Engineer David W. Barfield on September 18, 2009.

9. Letter dated September 18, 2017, to Joseph Pajor, City of Wichita, from David W. Barfield, Chief Engineer, RE: Wichita ASR project, Process and input on City's technical work.
10. Letter dated March 12, 2018, to David W. Barfield, Chief Engineer, from Alan King, Director of Public Works and Utilities, City of Wichita, RE: City of Wichita ASR Permit Modification Proposal.
11. Report dated March 12, 2018, ASR Permit Modification Proposal Revised Minimum Index Levels & Aquifer Maintenance Credits, prepared for the City of Wichita, Kansas by Burns and McDonnell, Project No. 71395.
12. Letter to Groundwater Management District NO 2 and City of Wichita from David W. Barfield, Chief Engineer, re: City of Wichita ASR Project New Applications, File Nos. 48,704 through 48,733 and proposed modified Phase II approval, with attached "Initial Draft for review, March 22, 2018 Proposed Replacement F & O for ASR Phase II".
13. Letter dated April 27, 2018, with attachments, to David W. Barfield, Chief Engineer, from Tim Boese, Manager, Equus Beds Groundwater Management District No. 2 Re: City of Wichita Aquifer Storage and Recovery Project Proposed Permit Modifications.
14. Letter dated May 22, 2018 to David W. Barfield, Chief Engineer, from Alan King, City of Wichita, RE: City of Wichita Aquifer Storage and Recovery (ASR) Permit Modification Proposal.
15. Letter dated June 1, 2018, to Groundwater Management District No. 2 and City of Wichita, from David W. Barfield, Chief Engineer, with attached "Responses to GMD 2 legal/policy questions and comments".
16. KDA-DWR Summary: "Wichita Aquifer Storage and Recovery project proposed changes", dated June 28, 2018.
17. Copies of PowerPoint presentations from the Division of Water Resources, Kansas Department of Agriculture, City of Wichita and Equus Beds Groundwater Management District No. 2, at the June 28, 2018, Public Information Meeting regarding the Wichita Aquifer Storage and Recovery project proposed changes.
18. KDA-DWR Summary: "Wichita Aquifer Storage and Recovery project proposed changes", dated December 11, 2018.

I expect to be compensated at the rate of $200 per hour for study, preparation and testimony in this case.

The foregoing report is true and correct to the best of my knowledge.

Executed on February 18, 2019.

David L. Pope

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